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Monterey, California



CONTRACTOR REPORT

FURTHER DEVELOPMENT OF A DUAL-PROBE DIGITAL
SAMPLING (DPDS) TECHNIQUE FOR
MEASURING FLOW FIELDS IN ROTATING MACHINES

F. Neuhoﬀ
BDM Corporation
P.O. Box 2019
Monterey, CA 93940

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Rear Admiral J. J. Ekelund
Superintendent

D. A. Schrady
Provost

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This report was prepared by:

WILLIAM M. TOLLES
Dean of Research

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digital data sampling, to obtain the blade-to-blade velocity field in a machine are documented with examples of results. Successes and potential problems are evaluated.

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1. INTRODUCTION

The development of the measurement technique reported here was required for the determination of the periodic flow field behind the rotor of a small, single-stage axial compressor. With the rotational speed of the rotor of 30,000 RPM at design conditions, the 18 blades of the rotor result in a blade-passage frequency of 9 KHz. Thus a high response measurement technique was essential. As reported earlier in Ref. 1, the means for determining the time-averaged flow at all speeds is available, and such measurements have been made to 50% speed.

The basic idea of the present technique was established some time ago (Refs. 2, 3, 4). This report gives a brief review of the measurement concept, results obtained with a first set of probes, and describes in detail the calibration and application of a new set of probes. The new probes have the advantage of being only two-thirds the size of the old ones.

2. MEASUREMENT CONCEPT

As described in detail in Ref. 2, a dual-probe digital sampling technique is used to determine the flow field behind the rotor in a real time regime. The technique incorporates two high response Kulite pressure transducers (Fig. 1). Using two trigger signals from the compressor shaft (one per revolution and one per blade), digitization of signal data can be controlled from the probes which are shown in Fig. 2. 128 locations can be selectively triggered for any one blade passage, thus giving good resolution for the specific area to be covered. The control device for the computer acquisition of the data is the PACER. Details of this device, which was developed in-house, can be found in Refs. 2 and 3.

Two major changes to the hard- and software of the PACER were made recently which are reported in Ref. 4. These changes made the lock-on to blade passing frequency totally automatic and reliable, and significantly reduced the total time for acquisition of a set of data. During the period reported here, several errors were found in the work presented in Ref. 4; Appendix A identifies the errors and their corrections.

The measurement system consists of two pressure probes, one the so-called type "A" probe which is essentially a total pressure probe, and the so-called type "B" probe, a total

pressure probe bent up 35° from the zero pitch, zero yaw axis, in the plane of zero yaw. The PACER allows data to be acquired from each of the two probes when they are at identically the same location with respect to the rotor. The probes can be rotated about the sensor tip. It is noted that their outputs when set at different yaw angles could as well be considered as the output of different probes of fixed geometry. Earlier studies have shown the dependency of a total pressure and a type "B" probe on yaw angle. Appendix B gives a brief discussion and outlines the use which can be made of the probe characteristics.

In knowing the output for a certain yaw angle of the "A" probe and its output for zero yaw angle, as well as the output of the "B" probe for zero yaw angle at the same relative location, three different pressures are known for what might be considered to be a single equivalent multi-sensor probe. Reference 1 shows how such pressures can be reduced to values of pitch, yaw, and magnitude of the velocity vector. The zero yaw angle must be found first by comparing the left- and right-hand sides of the type "A" probe output as a function of yaw.

As shown in Appendix B, the type "A" probe output as a function of yaw angle in a steady uniform flow is symmetrical about a position where the probe is aligned with the flow (referred to as the zero yaw position). If in an unknown flow the yaw angle is not zero, by rotating the probe and

finding two equal pressure readings separated by a certain angle difference and selecting the mid-point between the two corresponding angles, the unknown yaw angle can be determined. This procedure is in principle the same as the pneumatic balancing of a conventional probe (see Ref. 1). However, in an actual measurement situation the pressure output is not given as a continuous function of yaw angle. In practice, the data acquisition system allows digital recording of data for 5 to 11 different probe yaw angles. Figs. 3(a) and 3(b) give a comparison of calibration data and an approximation using a fourth-order polynomial for nine data points. It is evident that the characteristics of the probes allow a good representation of their output to be obtained for $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ (α = yaw angle) if only a few values are given. From these analytic functions the values $P_{A \text{ max}}$ (maximum output of the "A" probe), $P_{B \text{ max}}$ (maximum output of the "B" probe) and a value P_{SA} can be determined very easily. P_{SA} is found from $P_A = P_A(\alpha)$ where a difference in yaw of 126° separates right and left branches. This difference is chosen because for $\pm 63^\circ$ of yaw the type "A" probe output corresponds closely to static pressure.

Details of the methods used to derive the pitch angle and Mach number from the values of $P_{A \text{ max}}$, P_{SA} and $P_{B \text{ max}}$ will be discussed later in detail.

In acquiring data from the compressor at a steady operating condition, for each of 128 positions in the blade-to-blade

direction across a selected blade passage, pressure data are acquired from the two probes set at 5 to 11 probe yaw angles. Thus at each blade-to-blade position $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ can be approximated and yaw and pitch angles and Mach numbers can be derived.

3. SECOND GENERATION PROBES

In order to improve spatial resolution and keep effects such as the probe stem interference as small as possible, a new set of Kulite probes was built.

3.1 Probe Design

The so-called second-generation probes incorporate Kulite semi-transducers of the type XC062. The transducers measure 0.062 inches in diameter and are roughly two-thirds of the size of the first generation transducers. Figure 4 shows the probes in detail. The other difference compared to the first probes is the angle of the tip of the "B" probe; it is at 35° rather than 55° with respect to the zero axis. The reason is that for a range of 30° to 50° angle of attack the relationship between pressure output and angle of an inclined pressure probe is almost linear, while for higher angles it can reach a minimum and become double valued. An angle of 35° should give good resolution for pitch angles in the range of -5° to $+15^\circ$.

The probe tips are covered with machined caps which have eight holes arranged in a circle. This way the area where the transducers are located is shielded while there is still sufficient area for the air to get into and out of the minute volume above the membrane. A frequency response in excess of 100 Khz is retained when the screen is used.

3.2. Temperature Sensitivity

High response semiconductor transducers are generally sensitive to temperature changes. That is, changes in the temperature of the surrounding medium will produce changes in the indicated pressure although there has been no change in the pressure level. In the transducer manufacturer's specifications it is quoted that a change of 100°F might result in a misreading of as much as 2% of the full range (25 PSI) of pressure. On request the transducers can be built so that only 0.5% misreading for the same conditions should result. Thus a 100°F temperature change should produce no more than 0.125 PSI or--equivalently--3.46" H₂O misreading.

The relationship between transducer voltage output and pressure is known to be linear (Refs. 2 and 3). Temperature changes result mainly in a shift of the intercept rather than the slope of the linear relationship. Since the temperature of the flow in the compressor is expected to be about 50°F higher than ambient, an error of 1.7" H₂O might be expected to be present in the pressure measurement if no account was taken of the temperature sensitivity, assuming the manufacturer's specification to be accurate.

A simple test was made to check the temperature sensitivity of the "B" probe. The probe was inserted into a container which was vented to atmospheric pressure but which could be heated. With the probe connected to the data

acquisition system in the usual way, the container temperature was changed and the voltage output of the probe was recorded. Figure 5 shows the effect of a temperature change of about 60°F over a period of four minutes. A corresponding increase of some 2.4" of water in the indicated pressure was observed, corresponding to about 0.6% of the full transducer range for a temperature change of 100°F. This was consistent with the sensitivity quoted by the manufacturer.

For an average flow Mach number in the compressor of 0.7, with a corresponding dynamic head of 154 inches of water, an apparent shift in the transducer intercept of 1 to 2 inches of water is not large. Also, since the shift would be similar at different probe angles (assuming the transducer temperature would not change significantly), measurements based on differences between pressures from the same probe set at different angles, would be little affected. However, as readings from the "A" and "B" probe are both involved in calculating the pitch angle, the probes must give absolute pressure levels accurately. Therefore there is need for on-line calibration as data is acquired at any new test condition.

4. PROBE CALIBRATION

4.1. Calibration Procedure

The range of Mach number, pitch and yaw angle over which the probes were calibrated, had to cover the ranges which were expected in the compressor measurements. The freejet used for the calibration, which is described in Ref. 1, is capable of Mach numbers up to 0.9, pitch angles from -45° to $+45^{\circ}$ and yaw angles from 0° to 360° . Figures 6(a), (b) and (c) show details of the probe hook-up and instrumentation which was used. Table I gives the input/output assignment list for the data acquisition system.

The "A" and "B" probes were calibrated separately. The probe outputs were each recorded for a total of 9 pitch angles (-15° to $+25^{\circ}$ in 5° increments) and 6 Mach numbers (0.2 to 0.7 in 0.1 increments). For each of these 54 configurations the probes were yawed from -80° to $+80^{\circ}$, as data were continuously recorded. This procedure served to establish the complete pressure vs. voltage output characteristics of the probes, information to be used later in the analysis and interpretation measurements in the compressor.

The transducers were scaled using bridge adjustments to give engineering units on the DVM. The angle potentiometer was set to read linearly in increments of 0.1° .

The Kulite transducers were scaled to read in increments of .01 inches of water, differential pressure. The slope and intercept of the Kulite transducer were checked and adjusted as necessary before taking data at each new test condition. The intercept was adjusted to zero by applying the jet reference stagnation pressure to the reference side of the probe transducer with the probe tip aligned with the flow and balancing the transducer bridge. The slope was set by adjusting the output of the transducer to be equal to the jet stagnation pressure with atmospheric pressure as reference.

For each configuration of probe, Mach number, and pitch angle, the procedure was as follows:

- (i) Reference measurements for the jet (stagnation pressure and temperature, and ambient pressure) were recorded.
- (ii) The probe was swept steadily from -80° to $+80^{\circ}$ yaw angle as 150 data values of both probe voltage output and yaw angle potentiometer reading were acquired by the computer (Fig. 6). The jet reference measurements were recorded again.
- (iii) The procedure in (ii) was repeated but with the probe yaw angle swept back from $+80^{\circ}$ to -80° .

The three sets of reference measurements were compared to verify the steadiness of the test conditions. When all data were taken, a printout was produced on the line printer and a plot of pressure versus yaw angle was generated on the X-Y plotter.

For each probe, the procedure in (i)-(iii) was repeated for each pitch angle with the jet Mach number fixed. The jet Mach number was then adjusted to the next value and the complete procedure repeated again.

4.2. Data Acquisition and Storage

For each of the 54 configurations a total of 640 numbers were stored in one data file as a 2 by 320 array. The computer program used for the data acquisition was &KALIB (on cartridge 26, FORTRAN IV). The program is listed in Appendix C together with program &YAW (on cartridge 26, FORTRAN IV). Both programs (&KALIB and &YAW) are acquisition programs for the calibration of type "A" and "B" probes. The difference is that program &YAW records--in a more conventional way--data from one fixed yaw position as the average of ten readings for up to 31 positions, while program &KALIB gathers data for continuously varying yaw position.

It was found that the average of multiple samples taken at a fixed yaw position did not give more accurate results than a single reading. Figure 7 shows a comparison between the output obtained with the two different data acquisition methods. The good agreement is an indication of the steadiness of the flow in the free jet. Figure 8 shows the output of a total pressure Kulite probe held fixed in the jet over a period of 4 minutes, during which 1000 single readings were recorded. The

largest disturbances shown in Fig. 8 are probably the result of distinct changes in the ambient pressure resulting from doors being opened or closed in the building, rather than fluctuations in the jet itself.

The data acquisition program &KALIB is fairly simple and contains explanations in the program listing. Details of the data arrangement in the array are given in the program listing (Program &KALIB, statement numbers 46 through 77).

4.3. Type "A" Probe Results

Figure 9 gives an example of the type "A" probe data output at fixed Mach number for each of nine pitch angles. Shown is the probe voltage output versus yaw angle. Such plots provided a visual check of the acquired data. Table II gives an example of the data recorded for one Mach number and one pitch angle for the "A" probe. All the data in Table II are stored in one file for each configuration. Table III gives a guide to the data files for the "A" probe calibration. They are stored on cartridge 26. The file names follow the following logic:

X Y K Z R R

where

X = A for the "A" probe, or = B for the "B" probe

Y = 2, 3, 4, . . . --Mach number x 10

K = K, Kulite

$Z = P$ for positive or $= N$ for negative pitch angle

RR = 15, 10, 05, etc., = magnitude of the pitch angle

All data taken for the "A" probe appeared to be well behaved and useful throughout.

4.4 Type "B" Probe Results

First measurements with the "B" probe showed poor to unusable results. The output of the probe as a function of yaw angle was unsymmetrical for positive or negative yaw angles. Figure 10 shows the output at one Mach number, for the full range of pitch angles. An investigation of the probe tip under the microscope showed that some of the holes in the protective screen at the probe tip were partially blocked by particles of dirt or glue (Fig. 11(a), and (b)). The holes were cleaned and the calibration rerun. Figure 12 shows the results at a Mach number of 0.4. The characteristics of the probe were seen to be much improved and satisfactory for the intended application. Table IV gives the list of the data file names as stored on cartridge 26.

4.5. Calibration Data Analysis

For the "A" probe the output of the probe as a function of yaw angle $P_A = P_A(\alpha)$ was analysed for each of the combination of Mach number and pitch angle. First, the maximum value, $P_{A \text{ max}}$, was calculated as the maximum value of a fourth-order polynomial curve fit in the

$-20^{\circ} \leq \alpha \leq 20^{\circ}$. Over this limited range the curve $P_A = P_A(\alpha)$ was fairly flat and a very precise determination of the maximum value was possible. Second, to establish values of P_{S_A} for each curve, (see Section 2), the data were surveyed to find the yaw angle closest to -63° . Data at this and at four values above and four values below this particular yaw angle were approximated with a second-order polynomial and the corresponding value of P_A , designated $P_{S_{A_L}}$ yaw was calculated. A second-order polynomial approximation for this part of the curve was adequate since the characteristic was nearly linear in this range (see also Appendix B). The same procedure was used for the right hand side of the characteristic to establish the value, $P_{S_{A_R}}$, at a yaw angle of $+63^{\circ}$. The two values were found to be the same to within a small deviation for all 54 configurations. The value of P_{S_A} was calculated as the average of $P_{S_{A_L}}$ and $P_{S_{A_R}}$. Figure 13 is an illustration of the data reduction.

The only data needed from the "B" probe was the maximum pressure output at each test condition. This value always occurred for a yaw angle of zero degrees when the flow was aligned. The maximum was found by approximating the output values of P_B over the yaw angle range $-30^{\circ} \leq \alpha \leq 30^{\circ}$ with a fourth-order polynomial and solving for zero slope. The corresponding yaw angle was found to be very close to zero for all 54 configurations.

Figure 14 shows a curve $P_B = P_B(\alpha)$ for one Mach number and one pitch angle with the value established for $P_B \text{ max}$.

The values of $P_{A \text{ max}}$, P_{S_A} , and $P_{B \text{ max}}$, so derived, were considered to be analogous to the outputs of a conventional pneumatic multi-sensor probe. The calibration and reduction of measurements to values of Mach number and pitch angle (the yaw angle was always zero) could be handled in exactly the same way as was done for the combination temperature-pneumatic probe (see Ref. 1). The dimensionless velocity, X , was used instead of the Mach number, M where X is defined as $X = \frac{V}{V_t}$ where $V_t = \sqrt{2 C_p T_t}$, the "limiting" velocity. The quantity X can be expressed in terms of Mach number as

$$X = \frac{\frac{\gamma-1}{2} M^2}{1 + \frac{\gamma-1}{2} M^2}$$

For each of the 54 test conditions, using the values $P_{A \text{ max}}$, P_{S_A} , and $P_{B \text{ max}}$, the coefficients β and γ were calculated where

$$\beta = \frac{P_{A \text{ max}} - P_{S_A}}{P_{A \text{ max}}} \quad (1)$$

$$\gamma = \frac{P_{A \text{ max}} - P_{B \text{ max}}}{P_{A \text{ max}} - P_{S_A}} \quad (2)$$

and a third coefficient, δ , was examined where

$$\delta = \beta \cdot \gamma$$

β is derived from values of the "A" probe only. The "A" probe is insensitive to pitch angle as long as it does not exceed $\pm 15^\circ$ to $\pm 20^\circ$. Hence γ provides the measurement of the pitch angle. The coefficients β , γ , and δ are discussed in detail in Ref. 1.

The data for a complete calibration are given in Table V. It can be seen that at fixed Mach number the value of β is always about the same regardless of the pitch angle while γ changes significantly with pitch angle. The changes in γ with changes in Mach number are seen to be small.

If X is expressed as a function of β and γ , $X = X(\beta, \gamma)$ and ϕ , the pitch angle is expressed as a function of β and γ , $\phi = \phi(\beta, \gamma)$ the functions $X(\beta, \gamma)$ and $\phi(\beta, \gamma)$ can be approximated with polynomials using the methods described in Ref. 6, such that

$$X = \sum_{i=1}^L \left\{ \sum_{j=1}^M C_{ij} \beta^{(j-1)} \right\} \cdot \gamma^{(i-1)}$$

$$\phi = \sum_{i=1}^L \left\{ \sum_{j=1}^M D_{ij} \beta^{(j-1)} \right\} \cdot \gamma^{(i-1)}$$

where C_{ij} and D_{ij} are constant coefficients. Figs. 15(a) and (b) show the surfaces which were obtained for $X(\beta, \gamma)$ and $\phi(\beta, \gamma)$, respectively.

The programs written to approximate $X = X(\beta, \gamma)$ and $\phi = \phi(\beta, \gamma)$, based on the subroutines given in Ref. 6, are &REST8 and &REST9. The programs are described in detail in Appendix D. It is noted that the coefficients were derived for the pitch angle expressed in radians.

A check of the approximation was performed in order to establish its quality. For the measurements of β and γ from the calibration X and ϕ were calculated using equations (3) and (4). The results were compared with the corresponding values known to have been set when the measurements were made. Errors in the dimensionless velocity, ϵ_X , and errors in the pitch angle, ϵ_ϕ , were defined as

$$\epsilon_X = \frac{X_m - X_c}{X_m} \cdot 100 \quad (5)$$

and

$$\epsilon_\phi = \phi_m - \phi_c \quad (6)$$

where the subscription m denotes the value measured or known to have been set and subscript c denotes the value calculated using the surface approximation.

The error ϵ_X is expressed as a percentage of the measured value while for the pitch angle the absolute difference in degrees between measurement and calculation is calculated. A percentage error in angle is meaningless close to **zero** pitch angle.

Table VI gives the coefficients obtained for the X and ϕ surfaces. Also shown are the errors ϵ_X and ϵ_ϕ obtained using equation (3) and equation (4). Approximations were derived for each of 36 possibilities consisting of combinations of first to sixth order approximation for β and first to sixth order approximation for γ .

The coefficients shown in Table VI gave the best results on average over the range of the calibration. They are stored as 7 by 7 arrays under the file names shown on cartridge 26. It is noted that the errors shown in Table VI are an indication only of the degree of accuracy of the approximation technique.

5. VERIFICATION TESTS

Two tests to evaluate the accuracy of the calibration and of the data reduction technique were made: (1) The raw data from the calibration were treated as test data and the reduction procedure to calculate X and ϕ was applied; (2) The probes were mounted together on the freejet, the flow was adjusted in Mach number and the two probes were set together to the same pitch angles, which were unknown to the operator (see 5.2.). Data were acquired at specific yaw angles and reduced as in the compressor application. The results are described in the following paragraphs.

5.1. Verification Using Calibration Data

From the calibration test, the pressures for the "A" and "B" probe were recorded for fixed Mach number and pitch angle as $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ for a range of yaw angle of $-80^\circ \leq \alpha \leq 80^\circ$. These distributions were each approximated using a sixth order polynomial, so that values P_A and P_B could be interpolated at any yaw angle. For the "A" probe 9 yaw angles were chosen ($\pm 65^\circ$, $\pm 45^\circ$, $\pm 30^\circ$, $\pm 15^\circ$, 0°) so that the range of yaw angle necessary to handle the data reduction was covered. Since for the "B" probe sufficient values are required to determine only the maximum output, 9 different yaw angles for a

relatively small range were chosen ($\pm 30^\circ$, $\pm 22.5^\circ$, $\pm 15^\circ$, $\pm 7.5^\circ$, 0°). Arrays PA(9) and YAWA(9) were generated to contain pressure and yaw angles respectively for the "A" probe and similarly PB(9) and YAWB(9) were generated for the "B" probe. These data were then in a format as if they were produced by the data acquisition program for compressor measurements, and could be reduced in the same way.

From the fourth order polynomial for the "B" probe data, the maximum value P_{Bmax} and yaw angle at which it occurred were stored, for each data set.

PA(9) vs. YAWA(9) and PB(9) vs. YAWB(9) were approximated using fourth order polynomials. For each data set the curve $P_A = P_A(\alpha)$ was searched for the yaw angles where the spread between left and right branches was 126° . Corresponding to definitions used in the reduction of calibration data, the pressure determined at the left branch was P_{SA_L} and the one at the right branch was P_{SA_R} . These pressures were as defined here, the same and were equivalently equal to the value P_{SA} (see Fig. 13). P_{Amax} was calculated using the fourth order polynomial $P_A(\alpha)$ at the value of yaw angle midway between the values corresponding to P_{SA_L} and P_{SA_R} .

β and γ were calculated using equations (1) and (2) for each data set. Using these values, the coefficients from data files MISTXV and MISTIFI and the equations (3)

and (4), the corresponding values of X and ϕ were computed. The yaw angle was taken to be that corresponding to the value P_{Bmax} because the "B" probe had a clearly defined maximum whereas the "A" probe did not (see Figs. 13 and 14). The values so obtained for X , ϕ , and α using this reduction technique were compared to the corresponding values known to have been set and recorded during the test. Errors were calculated following equations (5) and (6). A third error, ϵ_α , for yaw was calculated using

$$\epsilon_\alpha = \alpha_m - \alpha_c \quad (7)$$

where α_m was the measured yaw angle and α_c was the yaw angle calculated from the "B" probe data. Since α_m was always zero during the calibration, the error ϵ_α so defined was equal to minus the value calculated in the reduction procedure.

The calculations described required extensive data handling. A program was written (EVALU) to read the two data files (for the "A" and "B" probes) and carry out the calculations. The program accesses and reduces data for one configuration (Mach number and pitch angle) at a time. It prints the calculated and measured values and the errors defined in equations (5), (6), and (7) before returning automatically to read the files for data from the next configuration. Program EVALU is described in detail in Appendix E.

Table VII shows a comparison of the measured and calculated data. Values for Mach number from 0.3 to 0.7 and pitch angle between 0° and 15° are given since these are the range of values expected in the intended application. The average error in X (or velocity) was about -0.4% with a maximum value of -1.336%. The average pitch angle error was 0.12° with a maximum value of 1.36° . An average yaw angle error of 0.6° was obtained with a maximum error of -1.16° . Figure 16(a), (b) and (c) show these errors plotted as functions of Mach number and pitch angle. No significant trends were detected in these data except perhaps in ϵ_{α} . Table VII shows that the yaw angle error was always negative at an average magnitude of roughly half a degree. This is probably an indication of the fixed error involved in mounting the probe on the freejet.

It should be noted that the probe mounting used on the freejet and on the compressor were not the same. After the calibration and verification tests were made on the freejet, the probes were mounted in special actuators for use on the compressor. First however, the assembled probe and actuators were mounted in turn on a six foot long, four inch diameter pipe which was fed by the laboratory air supply. In this pipe, due to its length to diameter ratio, a steady symmetrical airflow parallel to the pipe centerline was assured. For

different Mach numbers--pitch angle was constrained to zero degrees--each probe was yawed about its tip to either side. By comparing left and right branches of the indicated probe output the yaw angle vernier was set to zero at the point of symmetry, corresponding to aligned flow. The probe was secured in the actuator so that for compressor measurements, zero yaw corresponded precisely to alignment with the axial flow direction through the machine.

5.2. Verification on the Freejet

In order to verify the probe calibration and data reduction in a known flow, the probes were mounted together on the freejet. Only the yaw angle of one probe (the "A" probe) could be read using the data acquisition system. The probes were displaced peripherally at an angle of 90° to each other (see Fig. 6). While the tip of the "B" probe was on the centerline, the tip of the "A" probe was retracted radially about one inch from the centerline to avoid flow interference between the probes. Both probes were mounted on the same type of pitch angle adjustment device.

In the test procedure the probes were set in unison to controlled pitch angles and Mach numbers which were unknown to the operator. At each setting, the two probes were each rotated to 9 different yaw angles ($\pm 65^{\circ}$, $\pm 45^{\circ}$, $\pm 30^{\circ}$, $\pm 15^{\circ}$, 0°). Data were taken for each of the 9 yaw

positions. The pressure readings recorded were the average of 10 successive samples. Before the actual test the zero drift of the sensors was checked. For the "A" probe this was done by comparing the probe output when set to zero pitch angle with pressure. For the "B" probe, the probe was set to -35° in pitch (see Fig. 4) and a similar comparison was made. The data taken were not stored but only printed. Appendix F contains the computer program TEST which acquired the data and performed the data reduction.

In order to check the yaw angle determined by the reduction procedure the probe yaw angle data were artificially offset. The 9 yaw positions recorded were changed by adding a constant to each: $65^{\circ}+X$, $45^{\circ}+X$, $30^{\circ}+X$, $15^{\circ}+X$, $0^{\circ}+X$, $-15^{\circ}+X$, $-30^{\circ}+X$, $-45^{\circ}+X$, $-65^{\circ}+X$. The data reduction procedure should then produce a value for the yaw angle equal to X .

Table VIII shows results of the verification tests. Shown are the results for values of Mach number and pitch angle which are typical of those to be expected in the compressor. The errors given in Table VIII are defined as

$$\epsilon_X = \frac{X_S - X_C}{X_S} \cdot 100$$

$$\epsilon_{\phi} = \phi_S - \phi_C$$

$$\epsilon_{\alpha} = \alpha_S - \alpha_C$$

where index s is the set condition and c the calculated value.

The values of ϵ_X , ϵ_ϕ , and ϵ_α obtained were considered to represent an acceptable accuracy for the planned application of the technique. In particular, the accuracy of the pitch angle measurement was encouraging. The pitch angle was of particular concern because the distribution of pitch behind the rotor was a particular goal of the intended measurements which could lead to important conclusions concerning the flow through the rotor. As shown in Tables VII and VIII, the errors in pitch angle measurement appear to be acceptable.

6. APPLICATION IN COMPRESSOR TESTS

Complete results of compressor measurements made with the probe system will be reported later. Some initial measurements are reported here to examine and illustrate the reliability and accuracy of the probe system and of the data reduction. Since the data acquisition in the compressor is more complicated than in calibration tests on the freejet, the procedures and the programs used are described in detail.

6.1. Necessity of an Online-Calibration

The semi-conductor transducers are, to some degree, sensitive to temperature change as well as to differential pressure change. If a relationship between differential pressure and voltage output of the transducer was established by calibration before the compressor was started, there would be no guarantee that this relationship would remain valid while the machine was running. A total temperature rise of 25°F occurs in flow through the rotor and the actual temperature of the probe itself must increase, but can never be known precisely. The magnitude of the probe temperature rise is large enough however that the change in the transducer's voltage/pressure relationship must be taken into account in some

way. This is done through online calibration.

6.2. Online Calibration

Although there is a temperature sensitivity, the relationship between the voltage output of the transducer and the differential pressure is found to be always linear (Ref. 2, 3). Thus, if e denotes the voltage output and ΔP the corresponding differential pressure, the equation

$$\Delta P = i + S \cdot e \quad (8)$$

describes the calibration, where i is the intercept and S is the slope.

The transducer is arranged in the probes such that any desired constant pressure, P_r , can be applied to the back, or reference side, of the transducer. The unknown pressure on the front of the transducer, P , which is varying in time, is given by $P = \Delta P + P_r$, or

$$P = i + S \cdot e + P_r \quad (9)$$

The on-line calibration procedure establishes values for the slope and intercept while the compressor is operating at the speed and flow rate at which probe data are required. The procedure to establish the slope is the same for both the Type "A" and Type "B" probes. The procedure for the intercept is more elaborate and quite different for the two probes. The procedures are described separately in the following paragraphs.

6.2.1. Procedure For Slope

At a given steady machine condition, the time average probe pressure, \bar{P} , is constant. Because of thermal inertia it is reasonable to assume that both the slope S and the intercept i are also constant, although unknown. If two different reference pressures, P_{r1} and P_{r2} , are applied to the transducer in turn, and the corresponding time-averaged output voltages \bar{e}_1 and \bar{e}_2 are recorded then, from equation (9),

$$\bar{P} = i + S \cdot \bar{e}_1 + P_{r1} \quad (10a)$$

and

$$\bar{P} = i + S \cdot \bar{e}_2 + P_{r2} \quad (10b)$$

combining these equations, it follows that

$$S = \frac{P_{r2} - P_{r1}}{\bar{e}_2 - \bar{e}_1} \quad (11)$$

Equation (11) provides the means to calculate the slope of the transducer from measurements. In practice four to five different reference pressures are applied and the slope is calculated as a linear approximation (by least squares) to the variation of \bar{e} vs. P_r .

6.2.2. Procedure For Type "A" Probe Intercept

The time averaged flow conditions in the measuring plane are established using the combination pneumatic and temperature probe reported in Ref.1. The probe determines values for the Mach number, pitch angle

and yaw angle*. The combination probe tip, with its arrangement of four pressure tubes, is shown in Fig. 17. When the probe is aligned to balance pressures P_2 and P_3 , the pressure referred to as P_1 is a measurement of the total pressure, since the flow pitch angle can not exceed about 11° at the rotor exit. Similarly, the type "A" probe when aligned at the time-averaged yaw angle is also in principle, a total pressure probe. By equating the measured pneumatic pressure P , to be equal to the time-average of the pressure seen by the type "A" probe, $\overline{P_A}$, the intercept of the "A"-probe can be calculated using equation (10)**.

Data for the calculation of the intercept was gathered during the acquisition of time-resolved flow

*The question of whether a pneumatic probe can measure the correct time-averaged values of fluctuating pressures, raised in Ref. 7 and Ref. 8, was addressed in Ref. 1. It was shown that for the conditions measured to date, the results of the combination probe were accurate. Nevertheless, the possibility that an increase in rotor speed, resulting in higher fluctuation pressure amplitudes and pressure ratios, might affect the accuracy of the pneumatic measurements is accepted; and close attention will be paid to it in the future.

**The "time-average" voltage could be recorded using the integrating DVM or by acquiring a large number of discreet samples at arbitrary intervals using the HP 5610 A/D converter and computing the average. In early tests, the samples for the time-average measurements were taken using the A/D converter in the so called "free-run" mode. Roughly 1500 single data samples were collected over about 15 msec. A comparison of the average values acquired this way with those given by a digital voltmeter consistently showed agreement to within $\pm 0.5\%$. Subsequently, for convenience, the DVM was used to acquire values of the time-averaged voltage S from the Kulite probes during the online calibration.

data. At each yaw angle to which the two probes were set, readings of the probe transducer outputs were recorded using the DVM. Data from the combination probe were acquired also; however, the probe's yaw angle was not changed. The DVM voltage readings from the "A" and "B" probes were approximated as functions of the corresponding yaw angles by fourth order polynomials, $\overline{e}_A = \overline{e}_A(\alpha)$ and $\overline{e}_B = \overline{e}_B(\alpha)$. The maxima of these functions were derived mathematically and designated $\overline{e}_{A\max}$ and $\overline{e}_{B\max}$ respectively.

The value $\overline{e}_{A\max}$ was found to exist at a flow yaw angle very close to the yaw angle measured with the combination probe. For the A probe, a pressure coefficient was defined as

$$\overline{C}_{PA0} = \frac{\overline{P}_{A\max} - \overline{P}_S}{\overline{P}_t - \overline{P}_S} \quad (12)$$

The index "0" indicates that the coefficient was derived for the yaw angle where the probe was aligned with the time-averaged flow. Ideally \overline{C}_{PA0} would be unity, since the "A" probe is expected to measure total pressure if properly aligned with the flow. However, during the calibration procedure (reported in Section 4) it was found that \overline{C}_{PA0} depended slightly on the probe pitch angle, although not on Mach number. As shown in Fig. 18, \overline{C}_{PA0} varies within the range of 0.990 to 1.020. The

relationship between $\overline{C_{p_{A0}}}$ and pitch angle obtained in the steady-flow calibration was approximated by a fourth order polynomial. Using this approximation and the time-averaged pitch angle, stagnation pressure ($\overline{P_t}$) and static pressure ($\overline{P_s}$), $\overline{P_{Amax}}$ can be calculated using Equation (12).

Knowing the values $\overline{e_{Amax}}$, the slope s and the reference pressure (P_r), the intercept (i) of the A-probe can be calculated using equation (10). Thus the relationship between the probe and the time-varying voltage signal from "A" probe is known, using equation (9).

6.2.3. Procedure for Type "B" Probe Intercept

The determination of the intercept of the "B" probe is indirect. Unlike the "A" probe there is no matching pneumatic measurement for the "B" probe. Such an approach would be too inaccurate. The "B" probe is intended to be very sensitive to pitch angle changes, so that a very small difference in tip geometry of the Kulite and an "equivalent" pneumatic probe would cause a potentially large error in the calculation of the intercept. Thus an alternate way to derive the "B"-probe intercept was adopted.

During the online calibration procedure, the "A" and "B" probes are set to the same yaw angle as the combination probe. In this orientation, all three probes are aligned with the time-average flow vector. This flow vector is determined totally by the combination probe, and thus the yaw angle, pitch angle, Mach number, total and static pressures are known for the time-averaged conditions.

A pressure coefficients, $\overline{C_{PB}}$ can be calculated for the "B" probe using the definition

$$\overline{C_{PB}} = \frac{\overline{P_B} - \overline{P_S}}{\overline{P_t} - \overline{P_S}} \quad (13)$$

If the pressure reading of the "B" probe when aligned with the flow is referred to as $\overline{P_{Bmax}}$, the corresponding pressure

coefficient, \overline{C}_{PB0} , (at zero yaw angle of the probe with respect to the flow) is given by

$$\overline{C}_{PB0} = \frac{\overline{P}_{Bmax} - \overline{P}_S}{\overline{P}_t - \overline{P}_S} \quad (14)$$

From the calibration tests reported in Section 4, values of \overline{C}_{PB0} were determined for each of 54 combinations of Mach number and pitch angle. These data are given in Table IX. Figure 19 shows these calibration data for \overline{C}_{PB0} plotted as a function of Mach number and pitch angle. While the dependence on Mach number is seen to be small, a strong and well-behaved relationship between \overline{C}_{PB0} and pitch angle can be observed. \overline{C}_{PB0} was viewed as a function,

$$\overline{C}_{PB0} = \overline{C}_{PB0}(X, \phi) \quad (15)$$

The function in equation (15) was similarly approximated using the calibration data as a surface depending on two independent variables (Section 4.4). Appendix G describes the computer program used and illustrates the results.

Using the expression for the surface represented by equation (15), and values of the Mach number and pitch angle, given by the combination probe, at each operating point, \overline{C}_{PB0} were calculated. Then, using the time-averaged total and static pressures given by the combination probe measurement, a corresponding value of \overline{P}_{Bmax} can be calculated using equation (14). Using the recorded value of the

"B" probe voltage output, $\overline{e_B}_{\max}$, corresponding P_r , and the value established earlier for the transducer slope, the intercept of the "B" probe was calculated using equation (10). Thereafter, equation (9) could be used to convert time-dependent voltage readings to absolute pressure values.

6.3. Data Acquisition in TX-Compressor Measurements

The hardware of the dual probe digital sampling technique was described in Section 2. The present section describes the procedures and software used to acquire and store raw data necessary to determine blade-to-blade velocity distributions. The sequence of events is summarized in Table X.

As described in Section 2 and Section 4.5, at each blade-to-blade location sufficient data from the "A" and "B" probes were required that functions $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ could be established. However, the yaw angle was not known apriori for any of the 256 positions at which data were acquired. The time average yaw angle was known from the combination probe and variations in yaw angle were selected to be about this value.

It was found that yaw angle varied typically -5° to $+15^\circ$ from the time averaged value. Thus data were acquired for 9 different probe yaw angles covering a

range of the average yaw angle minus 5° minus 65° , and plus 15° plus 65° , in order to make sure that a sufficient range was covered to define the maximum values from $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ for $\alpha = \pm 63^{\circ}$.

Program &ABKUL was used for the data acquisition. It is described in detail in Appendix A. Figures 20a and 20b show an output of the raw data. Shown are the outputs of "A" probe (Fig. 20 a + b) & "B" probe (Fig. 20 c + d) for all 256 positions and for the 9 different probe yaw angle settings. The plots were generated by program &WAVE which is described in Appendix I. Besides plotting data from a data file the program also offers the possibility to acquire data from one Kulite probe and plot it on-line.

All data acquired with program &ABKUL are stored in one large data file. This includes the unsteady measurement data, all the steady state data for the online calibration and the combination probe measurements. Thus each data set is complete and independent of any other information.

Table Xa shows an example of steady state data acquired for the online calibration (see Section 6.2.); values for the slopes of the Type A before (1st) and after (2nd) the paced data acquisition. This output allows comparison of the results of the two calibrations. If the corresponding values of slope differ by more than $\pm 1.5\%$, which indicates drift during the measurement

period, the data are not accepted. The "intercepts" of "A" and "B" probes are also printed. These values are only used however to monitor changes during the data acquisition. The actual intercept of the voltage-pressure characteristic must be calculated from these values as described in Section 6.2. Here again a difference of more than $\pm 1.5\%$ is taken as evidence that the transducer drifted during the measurement. The other data shown in Table X is raw data which is printed out immediately after it is acquired so that it can be checked. Combination probe data are always acquired with the Kulite probe data. Table Xb shows steady-state data taken with the data from the "A" and "B" probes. For each probe yaw angle setting the same data is acquired as for the online calibration. The values "yaw A pr." and "yaw B pr." give the probe yaw angle settings (nine positions). In the third column values DCA and DCB are printed. As described in Section 6.2., these are the dc voltage levels of the "A" and "B" probes which will be used for the determination of the intercept. For each of the nine positions, values called "averaged values paced output" for "A" and "B" probes are printed. Those are the averages of the 256 single measurements of each of the probes. A comparison of these values with the DCA and DCB values--if the decimal point is neglected--show differences of up to 5%. This is

because the DC values are derived for the whole rotor, while the paced output values are from two selected blade pairs only.

The single raw data file is arranged in a 20 by 256 array. Table XI shows the location of the data within that array. Column #1 contains the data for the online calibration only while column #20 is reserved for the steady state data acquired with paced data. Columns #2 through #19 contain the raw data for the nine yaw angle settings of the "A" and "B" probe, with the Type A probe data in even numbered columns, the Type B probe data in the odd numbers. Table XI also shows the hook-up for the data acquisition for the steady state data. This is explained in more detail in Appendix H. The data acquisition for one set of data including online calibrations and steady state data requires some 17 to 20 minutes.

6.4. Data Reduction

After the raw data is checked for obvious errors using program WAVE (see section 6.3.) the data reduction is carried out using a single program "ABRED". The steps in the procedure are listed in Table J-1 and Appendix J describes the program in detail.

The program first reads the coefficient files for the calibration of the A- and B-probe as well as those for the combination probe. The operator is then asked for some input concerning the amount of output that is desired. The first

calculation is to determine the flow time-average properties from the combination probe measurements. The average of the readings obtained at the nine different Kulite yaw angle settings is computed since the yaw angle of the combination probe was not changed during the acquisition sequence. The results shown in Table XII are values for dimensionless velocity (X), yaw angle, pitch angle, total pressure and static pressure.

The second calculation uses these values and the acquired raw data for the online calibration to compute the intercept values of the "A" and "B" probes. It is at the user's discretion to output the steps in this process in order to check the calculations performed (see Appendix J).

The first reduction of Kulite data performed is for the time-averaged values from Kulite probe measurements. A DC voltage reading of both probes was recorded for each of the nine yaw angle positions the probes were set to. Using the results of the previously performed online calibration, absolute pressure values are calculated. These are placed in two arrays, PAA(9) and PAB(9). Arrays YAWA(9) and YAWB(9) are filled with the corresponding yaw angle values. Using fourth order polynomials a relationship is approximated giving pressures of "A"- or "B"-probe as functions of yaw angle. From these functions the values $P_{A \max}$, P_{S_L} , P_{S_R} , P_{S_A} and $P_{B \max}$ are derived as shown in 4.5. The flow yaw angle was assumed to be the one corresponding to $P_{B \max}$. However, it should be mentioned that the flow yaw angle derived from the A-probe

as the center value between the yaw angles corresponding to P_{S_L} and P_{S_R} deviates only slightly ($\pm 0.5^\circ$ to $\pm 1.0^\circ$) from the one found with the B-probe.

From these four pressures, coefficients β , γ and δ are calculated. Applying the calibration coefficients to these values X-- or Mach number -- and pitch angle are calculated. Thus the time average flow vector is determined. If it is compared to the one derived from the combination probe measurement, the differences turn out to be, typically

0.64% in Mach number

0.55° in pitch angle

0.63° in yaw angle

The magnitude of these differences is acceptable. Table XII shows results of an actual data set from a compressor test run. At the very top, values calculated from combination probe measurements are displayed followed by the results of the online calibrations for both "A" and "B" probe. Immediately thereafter the contents of the arrays PAA(9), PAB(9), YAWA(9) and YAWB(9) are given showing the average pressure values of both Kulite probes and their corresponding yaw angles for the overall flow measurement. The values P_{S_L} , $P_{A \max}$ and P_{S_R} derived from those are shown as well as the corresponding yaw angles. Next $P_{B \max}$ and the yaw angle for this pressure is given.

In the following line the actual flow quantities as derived from the "A"- "B" probes are listed. XU, XAX and

BETA2 are calculated from X, pitch and yaw angle, the circumferential speed and axial speed are printed also.

These values are:

XU = Circumferential speed (dimensionless)

XAX = Axial speed (dimensionless)

BETA2 = Relative flow angle in the measuring plane.

Once the overall flow vector is determined from the Kulite probes and compared to the results from the combination probe, individual measurements are reduced for any or all of the 256 positions. Whether all, one or any set of positions is reduced is operator-controlled by input parameters.

The same way the data reduction was carried out for the time-average flow vector the raw data for all 256 single positions are treated. Arrays PA(9) and PB(9) are filled with nine individual pressures of "A" and "B" probe which were derived from the raw data applying the results from the online calibration. The yaw angle settings YAWA(9) and YAWB(9) are the same nine values as before. Those are the same throughout the whole reduction since they are the ones the probes were set to. In Table XII the arrays of P_A , P_B , YAWA and YAWB are shown. Also given are arrays PAC(9), DPA, PBC(9), DPB. As mentioned previously P_A and P_B are approximated as functions of yaw angle by fourth order polynomials. In order to check the quality of that approximation, using the polynomials, values are calculated for the nine given yaw angles (PAC(9) and PBC(9)) and the difference between the measured pressure

value P_A or P_B and the calculated value PAC or PBC is displayed as DPA or DPB. As long as the values DPA and DPB are smaller than ± 2 inches of water (all pressures shown are in inches of water), it can be assumed that the approximation fits the data points sufficiently well.

Above the array of measured data are some reduced values. Again P_{SL} , $P_{A \max}$ and P_{SR} are printed with their corresponding yaw angles. Below the array, $P_{B \max}$ and the flow angle for this particular position are given. In the last line position number, beta, gamma, X-- or Mach number --, pitch angle and yaw angle for this position are given.

If a data reduction shall be performed for all 256 positions it is advisable to skip the print-out of the raw data and all intermediate steps (primary input). This way there will be only the print-out of the last line of Table XII for each of the positions.

6.5 Data Presentation and Evaluation

In chapter 6.4 the reduction procedure of the raw data to discrete values of X - (or Mach number), pitch angle and yaw angle for all or any of the 256 positions of measurement was described. All these flow parameters were stored in a single file and can be retrieved at any time. In order to get an idea of the flow behavior with respect to the rotor, the flow parameters were plotted as a function of the position within the rotor frame. Figure 21(a) shows the distribution of X ; Fig. 21(b) gives the yaw angle and Fig. 21(c) the pitch angle distribution. The programs used to generate these plots, namely PLOTX, PLOTY and PLOTP, are described in Appendix L.

The general behavior of the measurements was examined. For this, the assumption was made that the relative flow angle at the rotor trailing edge, β_2 , was constant for a given radius (see Fig. 22). Figure 23 shows the velocity triangles for the flow leaving the rotor. If β_2 and X_u , the circumferential velocity, are constant, any change in the Mach number of the relative flow will reflect in a change of yaw angle and Mach number of the absolute flow. Using the nomenclature in Fig. 23, at any given flow condition i the absolute velocity is given by

$$X_{v_i} = \frac{X_{u_a}}{\tan \beta_2 \cdot \cos \alpha_i + \sin \alpha_i} \quad (16)$$

Figure 24 shows X_{v_i} as a function of yaw angle. To be examined is the yaw angle corresponding to the minimum value of X_{v_i} . From Fig. 23 it can be seen that this yaw angle is $(90^\circ - \beta_2)$ which is indicated also on Fig. 24. Looking at Fig. 21(b) it was found that indeed the minima of X_{vel} correspond to a yaw angle of 39.11° .

Another characteristic point in Fig. 21(b) is the maximum value (48°) of the yaw angle. When X_{vel} was derived from equation 16 and from Fig. 24 for that yaw angle, a value of .1572 was obtained. This value was found to be consistent with the measured Mach number for that particular location.

7. DISCUSSION AND CONCLUSIONS

As pointed out in chapter 6.2 the absolute accuracy of the Kulite measurements is governed by the accuracy of the combination probe measurements. At higher Mach numbers yet to be measured, this may become a problem (see Ref. 1). Reference 7 shows that the pneumatic measurement might be incorrect if the fluctuations in pressure increase in amplitude beyond certain limits. Since the experiments of Ref. 7 were carried out using a totally different set-up for measurements of total and static pressures, the results are not directly comparable, however, an examination of the possible influence of such errors was attempted.

The assumption was made that P1 should be treated like a total pressure probe and P23 and P4 like static pressure probes. It was assumed that an error in the measurements of P1 and also in P23 and P4, or in P1 or P23 and P4 would occur at the same time, giving a total of three possible combinations.

An error of 10% defined according to Ref. 7 was assumed. Such an error resulted in an error of 0.25% in the absolute value of the total pressure and 0.5% in the static pressure. These errors applied to the data from data file AB1901 resulted in none of the three error combinations giving a significant change in Mach number and yaw angle distribution. The pitch angle showed the only significant dependence on these assumed errors. Figure 25 shows the comparison of calculated pitch

angle distribution with and without assumed errors. It can be seen that the biggest error was found for the case of a correct total pressure, but an incorrect static pressure (P23 and P4). An average difference of about one degree was found, and the distribution did not show any qualitative differences. Since the pitch angle could also be measured 0.5° too low (if P1 is measured incorrectly but P23 and P4 are measured correctly), the achievable accuracy of the pitch angle measurement is within a range of -0.5° to $+1.0^\circ$.

The basis of the method of application in the compressor is that the behavior of the probes as a function of yaw angle at each point in the rotor frame is the same as in a steady flow at the corresponding Mach number and pitch angle. The steady flow characteristic is known from the calibration. In order to examine the validity of this assertion, probe measurements were analysed for selected points of measurement with respect to the rotor frame. It was found that the B-probe produced the same characteristic P_B vs. yaw angle in its application as it did in its calibration. The type A probe however showed different results depending on the location of measurement. Figure 26 shows the output of the A probe reduced to values of C_{p_A} plotted in comparison with the curve of C_{p_A} as a function of yaw angle established during the calibration. It can be seen that for the time average values the agreement between test data and the calibration is very acceptable. It

is also acceptable for data from near mid passage. However, the same is not true for data in Fig. 26 from the rotor wake region. Going into the wake and out of it tends to skew the top of the function C_{pA} vs. yaw angle to different sides of the actual flow yaw angle. Near the center of the wake the probe characteristic appears to be similar to that established in the calibration. Four possible explanations for the skewing are considered:

- a) Flow temperature effect on the probe output depending on the different probe yaw angle settings.
- b) Probe interference due to "steady" gradient effect.
- c) Probe interference due to "unsteady" gradient effect.
- d) "Incorrect" averaging in a flow in which Mach number and flow angles are separately unsteady, and probe output is non-linear in M , α and ϕ .

The effect in (a) is not a probable explanation since the effect would be present also in positions outside the wake. It is also unlikely, because of thermal lag, that the sensor material could respond to the high frequencies of the wake fluctuations. The effect in (b) could give errors having the observed qualitative behavior.

In Ref. 9 it is shown that when a velocity gradient strikes a total pressure probe the apparent location of measurement tends to shift away from the center of the probe tip. The calculations carried out in Ref. 9 were applied to the geometry of the probes and flow parameters measured in the blade wakes

with the A-B probes. It was found that an apparent displacement of the order of 3% of the probe outer diameter was indicated to be possible. This was considered to be negligible. However, since the results in Ref. (a) were for impact probes at zero yaw angle to the flow direction, an experiment to verify the conclusion for the A-B probes yawed in a velocity gradient, is certainly desirable.

The possibility of an unsteady error which results from the behavior of the probe itself must be considered. However, it is noted that the error is only significant where the flow is unsteady in the rotor frame. This explanation would have to be accepted if all other explanations failed, and could be verified by independent non-intrusive measurements such as LDV. However, since the error appears only in the unsteady wake the most probable cause is thought to be (d).

The existence of unsteadiness of flow parameters in the wake region is clearly evident from oscilloscope observations. The observed fluctuations are oscillations in the probe output voltage (pressure) readings, which--in the data acquisition process--are ensemble-averaged over 40 samples to represent one value of pressure for a single measurement.

From the average pressure values, pressure differences and ratios are derived and reduced to obtain a velocity vector calculated in this way is the same as the average flow velocity vector. The question clearly, is whether the flow velocity vector calculated in this way is the same as the average flow velocity vector which could be obtained if the actual velocity

vector was known for the individual samples. Clearly, the probe output depends quite differently on variations in pitch, yaw and Mach number, and the fluctuations involve changes in all three.

A first attempt was made to examine the problem of averaging. Using calibration data, an array of three Mach numbers, three pitch angles and three yaw angles was selected. This resulted in a total of 27 possible flow vectors, for which the functions $P_A = P_A(\alpha)$ and $P_B = P_B(\alpha)$ were known. Since the flow yaw angle during a calibration is always zero, an "artificial" yaw angle was superimposed on the calibration data. For yaw angles different from zero, corresponding pressure values for the A and B probes were shifted by the amount of the superimposed yaw angle, but in the opposite direction.

In a first step the 27 flow vectors were averaged by averaging their velocity components U, V, W and calculating the corresponding single values for pitch angle, yaw angle and Mach number. Secondly, for each of the 27 vectors, data sets PA(9) and PB(9) (corresponding to nine different probe yaw angles) were built. These values were averaged to result in nine single values for PA, PB and corresponding yaw angles. The regular data reduction procedure was then applied and pitch angle, yaw angle and Mach number were calculated.

Differences between the two calculation methods were defined as:

$$\epsilon_X = \frac{X_{af} - X_{ap}}{X_{af}} \cdot 100$$

$$\epsilon_\phi = \phi_{af} - \phi_{ap}$$

$$\epsilon_\alpha = \alpha_{af} - \alpha_{ap} ,$$

subscript "af" meaning average from flow vectors and "ap" meaning average from pressure values.

The procedure was carried out for four different sets of data, each consisting of 27 different flow conditions.

Table XIV lists the range within which each of the flow parameters was varied and the differences resulting from the calculations. The differences obtained were not large, however it must be noted that the process of averaging which has been tested does not exactly simulate the one to which the A-B probes are subjected in the compressor. Further analysis is required to properly evaluate the effect of averaging on the probe data. In order to explain the skewing observed in the A-probe output in the wake regions, it would only be necessary to have fluctuations which were not symmetric with respect to the wake centerline, as is very likely to be the case in the wake of a highly loaded compressor blade.

In conclusion, the DPDS technique has been developed further to successfully measure three components of velocity in regions outside the unsteady rotor wake. The edges of the wake region and average conditions on the wake centerline are well defined. A limitation to the use of the present method within the wake region is thought to be due to the necessity for ensemble averaging. Further work is planned to resolve this question.

TURBOPROPULSION LABORATORY
 HP9830/21 MX Data Acquisition
 Port/Channel Assignments

Test A-B-Calibr

Run No. 1

Date Jan 1982

S.V. #	S.V. #	SCANNER #1 ch	SCANNER #2 ch	SCANNER #2 ch
1		0	0	40
2		1	1	41
3		2	2	42
4		3	3	43
5		4	4	44
6		5	5	45
7		6	6	46
8		7	7	47
9		8	8	48
10		9	9	49
11		10	10	50
12		11	11	51
13		12	12	52
14		13	13	53
15		14	14	54
16		15	15	55
17		16	16	56
18		17	17	57
19		18	18	58
20		19	19	59
21		20	20	60
22		21	21	61
23		22	22	62
24		23	23	63
25		24	24	64
26		25	25	65
27		26	26	66
28		27	27	67
29		28	28	68
30		29	29	69
31		30	30	70
32		31	31	71
33		32	32	72
34		33	33	73
35		34	34	74
36		35	35	75
37		36	36	76
38		37	37	77
39		38	38	78
40		39	39	79
41				
42				
43				
44				
45				
46				
47				
48				

Table I. Data Acquisition System Hook Up.

TUNNEL TEMP. DEG. F			TUNNEL PRESS. INCHES H2O			REF. PRESS. INCHES H2O			F. BARO INCHES HG			BEFORE READING		
102.071200			46.1391000			-4101000			30.0800000					
102.7652600			46.3000000			-4270000			30.1000000			BETWEEN READING		
102.4874300			46.1999970			-4290000			30.1410000			AFTER READING		
102.8558000			46.2000050			-4303333			30.1866700			AVERAGE VALUES		
YAMANO KULITEOUT CP			YAMANO KULITEOUT CP			YAMANO KULITEOUT CP			YAMANO KULITEOUT CP			YAMANO KULITEOUT CP		
-31.22	-39.9700	-1.872	51	-19.67	44.79000	969	121	47.480	31.43000	1.172	181	41.1400	38.23000	1.621
-31.32	-40.1700	-1.876	62	-19.57	45.51000	970	122	49.880	31.50000	1.178	182	41.750	38.32000	1.624
-31.34	-40.2800	-1.878	63	-19.51	45.99000	976	127	49.710	31.64000	1.182	183	49.750	38.99000	1.629
-31.75	-35.1700	-1.853	64	-18.35	45.59000	1.000	134	50.540	31.41000	1.191	184	38.330	35.43000	1.751
-32.22	-37.0300	-1.849	65	-18.42	47.16000	1.010	135	51.540	31.74000	1.197	185	31.800	37.17000	1.764
-32.70	-34.9200	-1.763	66	-17.97	47.37000	1.019	136	52.730	31.12000	1.201	186	33.770	37.72000	1.833
-32.90	-32.9100	-1.711	67	-18.61	47.82000	1.027	137	53.700	31.50000	1.207	187	31.920	39.33000	1.872
-32.67	-30.4900	-1.667	68	-11.63	47.83000	1.039	138	54.570	31.64000	1.217	188	30.440	40.52000	1.879
-32.70	-28.1400	-1.618	69	-10.49	47.89000	1.059	139	55.230	31.68000	1.243	189	29.630	41.73000	1.973
-34.35	-25.8200	-1.565	70	-9.270	47.83000	1.089	136	55.210	31.58000	1.216	190	27.740	42.10000	1.977
-35.58	-23.5000	-1.537	71	-8.210	47.83000	1.094	131	57.040	31.50000	1.187	191	26.550	43.09000	1.976
-35.17	-21.5300	-1.475	72	-8.740	47.57000	1.097	137	57.570	31.77000	1.181	192	31.450	43.71000	1.979
-35.20	-19.0700	-1.420	73	-5.560	47.11000	1.096	133	58.620	31.72000	1.137	193	33.130	44.78000	1.974
-35.71	-17.8200	-1.393	74	-3.660	47.31000	1.096	131	59.570	31.70000	1.131	194	31.740	44.85000	1.974
-35.91	-15.9400	-1.358	75	-2.890	47.29000	1.097	135	60.340	31.43000	1.103	195	26.720	44.89000	1.974
-36.93	-13.9200	-1.310	76	-1.400	47.36000	1.017	138	61.140	31.29000	1.083	196	18.990	45.23000	1.973
-37.17	-12.1700	-1.270	77	-1.550	46.90000	1.008	137	62.090	31.74000	1.133	197	17.660	45.45000	1.977
-37.16	-9.49000	-1.212	78	1.930	47.02000	1.011	138	63.190	31.29000	1.094	198	16.300	45.50000	1.974
-38.36	-8.74000	-1.153	79	2.930	46.98000	1.009	139	63.790	31.29000	1.086	199	17.120	45.59000	1.973
-38.43	-3.76000	-1.083	80	2.600	47.02000	1.011	140	64.550	31.29000	1.045	200	13.150	45.68000	1.973
-38.75	-1.38000	-1.035	81	3.480	46.51000	1.009	131	65.470	31.55000	1.113	201	11.810	46.52000	1.973
-38.84	5.00000	-0.965	82	4.570	46.77000	1.008	142	66.640	31.29000	1.084	202	11.130	46.57000	1.973
-39.45	2.63000	-0.914	83	6.180	46.70000	1.017	143	67.380	31.10000	1.081	203	8.270	46.78000	1.973
-40.30	4.52000	-0.861	84	7.000	46.76000	1.019	144	68.000	31.29000	1.073	204	6.140	46.80000	1.973
-40.38	6.54000	-0.835	85	7.840	46.73000	1.014	145	68.740	31.29000	1.069	205	4.810	46.83000	1.973
-40.90	8.82000	-0.810	86	9.470	46.21000	0.993	146	69.350	31.29000	1.069	206	2.800	47.00000	1.973
-40.87	10.29000	-0.815	87	11.110	46.20000	0.992	147	70.150	31.29000	1.069	207	5.800	47.04000	1.973
-40.34	11.36000	-0.779	88	12.130	46.05000	0.994	148	71.980	31.29000	1.069	208	1.190	47.09000	1.973
-40.17	13.61000	-0.749	89	13.210	45.81000	0.994	149	71.880	31.29000	1.069	209	1.980	47.09000	1.973
-40.45	15.30000	-0.735	90	14.280	45.43000	0.978	150	72.270	31.29000	1.069	210	0.240	47.09000	1.973
-40.45	16.67000	-0.734	91	15.450	45.70000	0.971	151	60.650	31.29000	1.069	211	0.000	47.19000	1.973
-40.49	17.26000	-0.732	92	16.590	45.78000	0.969	152	60.570	31.29000	1.069	212	0.000	47.09000	1.973
-40.45	19.13000	-0.717	93	17.930	45.75000	0.949	153	60.600	31.29000	1.069	213	0.000	47.09000	1.973
-40.97	20.49000	-0.717	94	18.540	44.51000	0.955	154	69.630	31.29000	1.069	214	0.000	47.09000	1.973
-40.38	22.04000	-0.700	95	19.610	44.42000	0.954	155	70.210	31.29000	1.069	215	0.000	47.09000	1.973
-40.34	23.50000	-0.701	96	20.110	43.76000	0.947	156	77.770	31.29000	1.069	216	0.000	47.09000	1.973
-40.34	24.97000	-0.653	97	22.530	43.81000	0.941	157	77.810	31.29000	1.069	217	0.000	47.09000	1.973
-40.65	26.25000	-0.661	98	23.410	42.70000	0.939	158	78.650	31.29000	1.069	218	0.000	47.09000	1.973
-40.82	27.41000	-0.656	99	24.610	42.70000	0.923	159	75.370	31.29000	1.069	219	0.000	47.09000	1.973
-40.77	28.89000	-0.619	100	25.670	42.59000	0.913	161	73.910	31.29000	1.069	220	0.000	47.09000	1.973
-40.71	30.29000	-0.607	101	26.830	42.20000	0.907	161	73.210	31.29000	1.069	221	0.000	47.09000	1.973
-40.77	31.46000	-0.604	102	27.730	41.91000	0.910	162	70.650	31.29000	1.069	222	0.000	47.09000	1.973
-40.75	32.79000	-0.613	103	28.750	40.84000	0.877	163	68.420	31.29000	1.069	223	0.000	47.09000	1.973
-40.77	33.89000	-0.627	104	30.170	41.16000	0.853	164	67.080	31.29000	1.069	224	0.000	47.09000	1.973
-40.75	35.20000	-0.628	105	30.940	39.48000	0.849	165	65.410	31.29000	1.069	225	0.000	47.09000	1.973
-40.75	36.50000	-0.628	106	32.150	38.56000	0.828	166	63.750	31.29000	1.069	226	0.000	47.09000	1.973
-40.70	37.44000	-0.613	107	33.550	37.57000	0.813	167	61.460	31.29000	1.069	227	0.000	47.09000	1.973
-40.71	38.13000	-0.615	108	35.950	37.58000	0.796	168	60.890	31.29000	1.069	228	0.000	47.09000	1.973
-40.71	39.28000	-0.645	109	36.630	36.23000	0.777	169	59.460	31.29000	1.069	229	0.000	47.09000	1.973
-40.71	39.50000	-0.648	110	35.260	35.73000	0.766	171	57.770	31.29000	1.069	230	0.000	47.09000	1.973
-40.65	40.19000	-0.649	111	36.290	34.41000	0.758	171	56.370	31.29000	1.069	231	0.000	47.09000	1.973
-40.67	41.60000	-0.681	112	37.660	33.75000	0.724	172	55.170	31.29000	1.069	232	0.000	47.09000	1.973
-40.68	41.26000	-0.688	113	39.750	32.19000	0.691	173	53.510	31.29000	1.069	233	0.000	47.09000	1.973
-40.74	42.30000	-0.664	114	39.940	31.40000	0.671	174	51.510	31.29000	1.069	234	0.000	47.09000	1.973
-40.75	42.80000	-0.615	115	40.420	30.31000	0.649	175	49.040	31.29000	1.069	235	0.000	47.09000	1.973
-40.83	43.67000	-0.625	116	41.350	29.45000	0.630	176	47.670	31.29000	1.069	236	0.000	47.09000	1.973
-40.87	43.61000	-0.632	117	42.750	27.77000	0.554	177	47.540	31.29000	1.069	237	0.000	47.09000	1.973
-40.89	44.41000	-0.651	118	44.110	26.14000	0.559	178	45.760	31.29000	1.069	238	0.000	47.09000	1.973
-40.92	44.29000	-0.682	119	45.180	24.79000	0.573	179	44.270	31.29000	1.069	239	0.000	47.09000	1.973
-40.90	44.77000	-0.682	120	46.410	23.32000	0.585	180	42.650	31.29000	1.069	240	0.000	47.09000	1.973

Table II. Raw Calibration Data From A-Probe, One Mach Number, One Pitch Angle.

0.7	A7KP25	A7KP20	A7KP15	A7KP10	A7KP05	A7KP00	A7KN05	A7KN10	A7KN15
0.6	A6KP25	A6KP20	A6KP15	A6KP10	A6KP05	A6KP00	A6KN05	A6KN10	A6KN15
0.5	A5KP25	A5KP20	A5KP15	A5KP10	A5KP05	A5KP00	A5KN05	A5KN10	A5KN15
0.4	A4KP25	A4KP20	A4KP15	A4KP10	A4KP05	A4KP00	A4KN05	A4KN10	A4KN15
0.3	A3KP25	A3KP20	A3KP15	A3KP10	A3KP05	A3KP00	A3KN05	A3KN10	A3KN15
0.2	A2KP25	A2KP20	A2KP15	A2KP10	A2KP05	A2KP00	A2KN05	A2KN10	A2KN15
Mach ↑	25	20	15	10	5	0	-5	-10	-15

Table III. Raw Data File Name Arrangements (A-Probe).

0.7	B7KP25	B7KP20	B7KP15	B7KP10	B7KP05	B7KP00	B7KN05	B7KN10	B7KN15
0.6	B6KP25	B6KP20	B6KP15	B6KP10	B6KP05	B6KP00	B6KN05	B6KN10	B6KN15
0.5	B5KP25	B5KP20	B5KP15	B5KP10	B5KP05	B5KP00	B5KN05	B5KN10	B5KN15
0.4	B4KP25	B4KP20	B4KP15	B4KP10	B4KP05	B4KP00	B4KN05	B4KN10	B4KN15
0.3	B3KP25	B3KP20	B3KP15	B3KP10	B3KP05	B3KP00	B3KN05	B3KN10	B3KN15
0.2	B2KP25	B2KP20	B2KP15	B2KP10	B2KP05	B2KP00	B2KN05	B2KN10	B2KN15
0.1	25	20	15	10	5	0	-5	-10	-15
Pitch ↑ Mach									

TABLE IV. Raw Data File Name Arrangements (B-Probe).

DATA STORED IN FILE ABNEW2.D (10.50)

(J,1)	(1,I)	(2,I)	(3,I)	(4,I)	(5,I)	(6,I)	(7,I)	(8,I)	(9,I)	(10,I)
	409.36	422.79	.0958	25	1.0540	.0030	64.41	.0329	.0269	
	409.37	422.99	.0962	20	1.0521	.0070	65.45	.0299	.0467	
	409.51	423.13	.0961	15	1.0593	.0290	65.75	.0316	.0130	
	409.54	423.02	.0960	10	1.0749	.0250	65.63	.0309	.0297	
	409.54	423.02	.0962	5	1.0803	.0660	65.64	.0299	.0665	
	409.68	423.33	.0965	0	1.0722	.6934	65.36	.0313	.3895	
	409.87	423.09	.0965	-5	1.0921	.7860	64.90	.0304	.2778	
	409.54	423.11	.0963	-10	1.0736	.8478	64.16	.0320	.2262	
	409.27	422.59	.0954	-15	1.0465	.7040	62.89	.0326	.1377	
	409.11	436.25	.1348	25	.9766	.0460	62.57	.0617	.9430	
	409.29	436.44	.1348	20	1.0036	.1270	63.59	.0614	.8122	
	409.29	436.39	.1347	15	1.0107	.3320	63.87	.0611	.6997	
	409.27	436.35	.1349	10	1.0065	.4260	63.79	.0612	.5874	
	409.29	436.36	.1346	5	1.0054	.6080	63.72	.0616	.5099	
	409.09	436.09	.1345	0	1.0157	.7290	63.25	.0620	.2864	
	409.38	436.75	.1353	-5	1.0067	.8240	62.62	.0641	.1785	
	409.95	435.84	.1343	-10	.9930	.8960	61.76	.0641	.0589	
	409.20	436.39	.1349	-15	.9422	.9190	60.51	.0650	.0323	
	409.52	456.95	.1754	25	.9598	.4930	62.36	.1033	.8231	
	409.29	456.46	.1752	20	1.0007	.7400	63.05	.1018	.7222	
	409.32	456.37	.1750	15	1.0050	.3810	63.43	.1019	.6312	
	409.61	457.19	.1750	10	.9964	.5160	63.50	.1030	.4937	
	409.16	456.24	.1750	5	1.0167	.6390	63.22	.1042	.3734	
	409.23	456.38	.1751	0	1.0209	.7430	62.94	.1094	.2567	
	409.11	455.83	.1744	-5	1.0146	.8510	61.94	.1095	.1544	
	409.09	455.82	.1744	-10	.9877	.9200	61.19	.1084	.0441	
	409.20	455.04	.1742	-15	.9669	.9520	60.00	.1100	.0139	
	408.84	484.07	.2171	25	.9541	.1220	62.37	.1523	.8482	
	408.84	483.67	.2165	20	.9790	.2250	63.26	.1522	.7107	
	409.00	483.70	.2163	15	.9898	.4130	63.67	.1519	.5957	
	409.04	483.58	.2161	10	.9941	.5450	63.55	.1513	.4847	
	409.64	483.04	.2160	5	1.0094	.6720	63.27	.1530	.3795	
	408.52	483.01	.2162	0	1.0051	.7270	62.74	.1548	.2929	
	408.68	483.15	.2161	-5	.9956	.8690	62.15	.1583	.1833	
	408.86	482.71	.2152	-10	.9901	.9370	61.12	.1635	.0805	
	408.86	482.98	.2156	-15	.9614	.9620	59.66	.1705	.0405	
	408.41	525.49	.2636	25	.9253	.1740	63.26	.2097	.8117	
	410.22	526.54	.2624	20	.9788	.3230	63.55	.2106	.6817	
	410.63	527.33	.2626	15	.9863	.4590	63.65	.2126	.5505	
	410.45	526.83	.2624	10	.9927	.6010	63.82	.2135	.4460	
	410.56	526.84	.2625	5	.9955	.7150	63.35	.2170	.3576	
	410.83	527.17	.2622	0	.9981	.8150	62.82	.2212	.2551	
	410.27	527.05	.2629	-5	.9775	.8860	62.03	.2298	.0887	
	410.06	526.98	.2630	-10	.9635	.9340	61.03	.2329	.0293	
	410.61	527.41	.2627	-15	.9329	.9690	57.90	.2433	.0334	
	410.65	564.62	.2949	25	.9721	.2140	63.53	.2608	.7937	
	410.11	563.23	.2944	20	.9935	.3590	64.04	.2580	.6699	
	410.24	563.46	.2944	15	.9973	.5010	63.04	.2543	.5311	
	410.79	564.32	.2945	10	1.0029	.6330	64.16	.2579	.3899	
	410.36	563.67	.2945	5	1.0014	.7450	63.56	.2675	.2606	
	410.54	564.31	.2948	0	1.0020	.8330	62.61	.2737	.1229	
	410.47	564.42	.2949	-5	.9870	.9020	62.22	.2743	.0848	
	410.63	564.76	.2950	-10	.9671	.9490	61.27	.2776	.0187	
(J,54)	410.47	564.84	.2952	-15	.9372	.9830	59.76	.2637	.0475	

Table V. All Reduced Data From File ABNEW2.

COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FILE :MIST: : 26 Final

M(order)	N(order) →	1	2	3	4	5
1	↓	.058417	-.066206	.293789	-.568494	.729473
2		1.343710	.681829	-1.353885	6.966662	-5.783688
3		-2.156698	-3.002923	-32.213394	14.260990	19.503295
4		-8.578531	85.379852	35.079987	-64.118652	12.651482
5		38.158485	-317.229310	435.952640	-382.115340	105.567090
		1	2	3	4	5

ERRORS AT EACH POINT

Mach	Pitch Angle →	1	2	3	4	5	6	7	8	-15°
Number	+25°	1	2	3	4	5	6	7	8	9
2		-2.342	2.054	.039	.790	-.310	-1.182	.638	-.357	-1.439
3		1.395	-.566	-1.149	-.499	.676	1.694	1.476	.808	.139
4		-.150	-.415	-.261	.563	.241	-1.955	-1.274	-.317	-.366
5		-.429	-.020	.757	.764	.122	-.051	.018	.450	.502
6		.244	-.377	-.147	-.299	-.555	.044	.126	.265	-1.492
7		.028	-.179	.290	.248	.035	-.088	-.474	.534	.355
		1	2	3	4	5	6	7	8	9

Table VI(a). Coefficients and Errors for Mach Number (X_{vel}) Approximation.

COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FILE :MIST: : 26 Final

M(order)	N(order) →	1	2	3	4
1	↓	-.774307	1.829133	-1.109611	.454293
2		14.616833	-17.081480	-12.211709	21.338826
3		-142.245970	100.290780	12.043030	-245.438090
4		520.891365	-329.110050	1012.021271	1138.625200
5		-858.544800	242.085880	-770.762800	-1743.12330
		1	2	3	4

ERRORS AT EACH POINT

Mach	Pitch Angle →	1	2	3	4	5	6	7	8	-15°
Number	+25°	1	2	3	4	5	6	7	8	9
2		1.452	-1.510	.219	-.174	-.090	1.056	-.743	-.609	-.058
3		-.381	.325	.269	-.164	.490	.248	.458	.311	.527
4		-.048	-.360	.106	-.043	-.605	-.698	-.453	.073	-1.409
5		-.116	.683	.359	.563	-1.526	.746	1.126	1.622	-.379
6		-.209	.082	-.376	.040	-.189	.180	.123	-.569	-.215
7		-.067	.284	-.072	-.390	.150	-.106	.327	-.163	.500
		1	2	3	4	5	6	7	8	9

Table VI(b). Coefficients and Errors for Pitch Angle (ϕ) Approximation.

CALCULATION			MEASUREMENT			ERRORS		
<u>X Vel</u>	<u>Pitch</u>	<u>Yaw</u>	<u>X Vel</u>	<u>Pitch</u>	<u>X Vel</u>	<u>Pitch</u>	<u>Yaw</u>	
[]	[°]	[°]	[]	[°]	[%]	[°]	[°]	
.1365	14.83	.69	.1347	15.00	-1.3357	.17	- .69	
.1358	9.96	.52	.1349	10.00	- .6396	.04	- .52	
.1343	5.03	.15	.1346	5.00	.2487	- .03	- .15	
.1332	.07	.40	.1345	0.00	1.0161	- .07	- .40	
.1766	14.75	.73	.1750	15.00	- .9074	.25	- .73	
.1755	9.87	.71	.1758	10.00	.1439	.13	- .71	
.1747	5.33	.68	.1750	5.00	.1923	- .33	- .68	
.1751	.22	.53	.1751	0.00	.0256	- .22	- .53	
.2155	14.04	.13	.2163	15.00	.3642	.96	- .13	
.2161	9.09	.64	.2161	10.00	- .0087	.91	- .64	
.2178	4.03	.80	.2160	5.00	- .8027	.97	- .80	
.2182	- 1.36	1.05	.2162	0.00	- .9259	1.36	-1.05	
.2643	15.36	.16	.2626	15.00	- .6210	- .36	- .16	
.2635	10.56	.08	.2624	10.00	- .4118	- .56	- .08	
.2639	4.02	.19	.2622	5.00	- .6578	.98	- .19	
.2643	.54	.91	.2622	0.00	- .8000	- .54	- .91	
.2960	15.20	1.01	.2944	15.00	- .5198	- .20	-1.01	
.2968	10.64	.38	.2945	10.00	- .8086	- .64	- .38	
.2978	5.03	.76	.2945	5.00	-1.1207	- .03	- .76	
.2944	.41	1.16	.2948	0.00	.1303	- .41	-1.16	
			Averages: -0.3717			+ 0.119	-0.504	

Table VII. Errors in Mach Number, Pitch and Yaw Angle for the Application of Calibration Procedure to Calibration Raw Data.

CALCULATED FROM				ADJUSTED				ERRORS			
MEASURED DATA				FREEJET VALUES							
<u>X Vel</u> []	<u>Pitch</u> [°]	<u>Yaw</u> [°]	<u>X Vel</u> []	<u>Pitch</u> [°]	<u>Yaw</u> [°]	<u>X Vel</u> []	<u>Pitch</u> [°]	<u>Yaw</u> [°]	<u>X Vel</u> []	<u>Pitch</u> [°]	<u>Yaw</u> [°]
.14206	.04	0.31	.1420	0	0	.1420	0	0	-0.04	-0.04	-0.31
.14373	4.74	-0.11	.1459	5	0	.1459	5	0	+1.49	-0.26	+0.11
.14368	4.79	0.1	.1459	5	0	.1459	5	0	+1.52	+0.21	-0.1
.14315	10.18	0.24	.1450	10	0	.1450	10	0	+1.28	-0.18	-0.24
.14483	14.82	- 0.3	.1448	15	0	.1448	15	0	-0.02	+0.18	+0.30
.16787	9.78	0.78	.170	10	0	.170	10	0	+1.22	+0.22	-0.78
.17199	8.97	5.46	.170	10	5	.170	10	5	-1.17	+1.03	-0.45
.17053	10.20	10.22	.170	10	10	.170	10	10	-0.31	-0.2	-0.22
.20382	7.66	- 0.18	.2049	7	0	.2049	7	0	+0.53	-0.66	+0.18
.21165	10.16	0.2	.211	10	0	.211	10	0	-0.31	-0.16	-0.2
.20467	13.21	0.24	.2052	13	0	.2052	13	0	+0.26	-0.21	-0.24

Table VIII. Errors in Mach Number, Pitch and Yaw Angle for A-B Probe Application
Test in Freejet.

.0958	25	.0030
.0962	20	.1470
.0961	15	.2790
.0960	10	.4250
.0962	5	.5680
.0965	0	.6930
.0965	- 5	.7860
.0963	-10	.8470
.0954	-15	.9040
.1348	25	.0460
.1348	20	.1970
.1347	15	.3320
.1349	10	.4760
.1346	5	.6080
.1345	0	.7290
.1353	- 5	.8240
.1343	-10	.8900
.1349	-15	.9190
.1754	25	.0930
.1752	20	.2400
.1750	15	.3810
.1758	10	.5160
.1750	5	.6390
.1751	0	.7480
.1744	- 5	.8510
.1744	-10	.9200
.1742	-15	.9520
.2171	25	.1290
.2165	20	.2750
.2163	15	.4130
.2161	10	.5480
.2160	5	.6720
.2162	0	.7770
.2161	- 5	.8690
.2152	-10	.9370
.2156	-15	.9620
.2636	25	.1740
.2624	20	.3230
.2626	15	.4590
.2624	10	.6010
.2622	5	.7150
.2622	0	.8150
.2628	- 5	.8860
.2630	-10	.9340
.2627	-15	.9690
.2949	25	.2140
.2944	20	.3590
.2944	15	.5010
.2945	10	.6330
.2945	5	.7450
.2948	0	.8330
.2948	- 5	.9020
.2950	-10	.9490
.2952	-15	.9830

Table IX. CpOB for All Calibration Configurations of Mach Number and Pitch Angle

Point #	Immer. comb. Immer. A pr. Immer. B pr.	yaw comb. yaw A pr. yaw B pr.	P1 DCB DCB	P23 P23 RPM	P4 T+ DTT
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1	.000897 .000901 .000909	.003009 .003102 .003005	.000369 .000023 -.001729	.000062 .000369 1525.00000	.000003 .000717 .000677
2	.000900 .000902 .000911	.003057 .003128 .003097	.000372 -.001640 -.003348	.000050 .000530 1525.00000	.000003 .000717 .000677
3	.000901 .000903 .000909	.003110 .003133 .003090	.000369 .000186 .000634	.000045 -.000245 1525.00000	.000107 .000717 .000675
4	.000901 .000901 .000911	.003100 .003109 .003096	.000371 .003789 .002112	.000056 .000002 1525.00000	.000003 .000717 .000675

Online calibration (File : 001901102)

Point #	Immer. comb. Immer. A pr. Immer. B pr.	yaw comb. yaw A pr. yaw B pr.	P1 DCB DCB	P23 P23 RPM	P4 T+ DTT
---------	--	-------------------------------------	------------------	-------------------	-----------------

1	.000901 .000902 .000911	.003063 .003031 .003098	.000370 .003704 .002926	.000060 0.000000 1525.00000	.000000 .000675 .000675
2	.000901 .000902 .000915	.003115 .003091 .003098	.000378 -.001584 -.003333	.000061 .000532 1525.00000	.000000 .000702 .000669
3	.000902 .000903 .000913	.003093 .003084 .003101	.000382 .006207 .004708	.000068 -.000245 1525.00000	.000007 .000675 .000675
4	.000903 .000902 .000910	.003104 .003082 .003099	.000378 .000649 -.001673	.000057 .000373 1525.00000	.000007 .000675 .000675

	A probe Slope	Intercept %	P probe Slope	Intercept
1st calibration	-.099068	.000370 %	-.096795	.0000
2nd calibration	-.100253	.000375 %	-.097386	.0000

ble X(a). On-line Calibration Data for Actual Compressor Test (run #119).

Point #	Inner Comb. Inner A pr.	Yow Comb. Yow A pr.	P1 DCA	P23 Prof	P1 DCE
1	.000901 .000903 .000913	.003047 -.004006 -.003985	.000372 -.001233 -.002172	.000066 .000003 1526.00000	.000005 .000-03 .000809
Averaged values	paced output	: A probe	: -.12831	B probe	: -.42748
2	.000902 .000902 .000911	.003060 -.002004 -.001975	.000372 .001488 -.000020	.000065 .000002 1527.00000	.000013 .00072 .00068
Averaged values	paced output	: A probe	: .15864	B probe	: -.00521
3	.000901 .000903 .000912	.003110 -.000037 0.000010	.000374 .003200 .001223	.000063 .000003 1527.00000	.000024 .000720 .000670
Averaged values	paced output	: A probe	: .33133	B probe	: .13341
4	.000901 .000902 .000913	.003050 .001471 .001502	.000369 .003291 .001961	.000067 .000001 1527.00000	.000006 .000740 .000691
Averaged values	paced output	: A probe	: .37954	B probe	: .12949
5	.000900 .000902 .000908	.003080 .002970 .002979	.000376 .003250 .002069	.000063 .000003 1527.00000	.000004 .000688 .000670
Averaged values	paced output	: A probe	: .38385	B probe	: .21974
6	.000900 .000901 .000911	.003023 .004466 .004509	.000376 .003570 .001906	.000074 .000002 1528.00000	.000019 .000692 .000665
Averaged values	paced output	: A probe	: .32362	B probe	: .19992
7	.000899 .000901 .000909	.003084 .006492 .006533	.000373 .002857 .021204	.000064 0.000000 1528.00000	.000004 .000690 .000671
Averaged values	paced output	: A probe	: .30028	B probe	: .11550
8	.000903 .000904 .000912	.003083 .008472 .008524	.000371 .001169 -.000529	.000073 .000001 1527.00000	.000014 .000694 .000687
Averaged values	paced output	: A probe	: .12077	B probe	: -.05694
9	.000900 .000901 .000910	.003074 .010957 .011028	.000375 -.002386 -.003602	.000062 1.000000 1526.00000	.000005 .000698 .000680
Averaged values	paced output	: A probe	: -.22715	B probe	: -.36723

Table X(b). Run Steady State Data From A-B Probe Measurement (run #119).

DATA(20,256)

DATA(2,256) DATA(3,256) DATA(4,256) DATA(5,256) --- DATA(18,256) DATA(19,256)

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RAW DATA FILE : AB1901:: 27

FLOW AVARAGED VALUES AS ESTABLISHED WITH THE COMBINATION PROBE

Ptotal(INCH H2O)	Pstatic(INCH H2O)	Xvel	Mach	Phi(deg)	Yaw(deg)
438.852110	402.299380	.15693	.35443	4.55	30.76

EQUATION FOR A-PROBE PRESSURE :

PA = 400.532230 + 9966.041000 * VOLTAGE(raw)*0.01 + PREF(INCH H2O)

CP0A = 1.00408 CP0B = .6394757

EQUATION FOR B-PROBE PRESSURE :

PB = 405.349850 + 9709.025400 * VOLTAGE(raw)*0.01 + PREF(INCH H2O)

PAA(##) PAB(##) YAWA(##) YAWB(##)

1	388.564	384.562	-40.060	-39.850
2	415.562	405.356	-20.040	-19.750
3	432.724	417.524	-.37000	0.00000
4	438.413	424.489	14.7100	15.0200
5	438.205	425.738	29.7000	29.7900
6	436.311	424.055	44.6600	45.0900
7	429.005	417.040	64.9900	65.3300
8	412.283	400.314	84.7900	85.2400
9	376.753	370.378	109.570	110.280

A-PROBE APPROXIMATION RESULTS : YAW = -32.03 30.97 9
 PRESSURE (INCH H2O) = 401.494630 438.987430 401.49
 CPAMAX = 1.0036

B-PROBE APPROXIMATION RESULTS : YAW0 = 31.1 PRESSURE (INCH H2O) =426.03

AVERAGE VALUE RESULTS FROM THE A-B SYSTEM:

BETA	GAMMA	Xvel	Pitch	Yaw	XU	XAX	BETA2
.08541	.34569	.15693	4.00	31.13	.24251	.13400	50.33

A-PROBE APPROXIMATION RESULTS : YAW = -33.87 29.13 5
 PRESSURE (INCH H2O) = 401.035520 439.204830 401.03
 CPAMAX = 1.0093

#	YAWA(I)	PA(I)	PAC(I)	DPA	YAWB(I)	PB(I)	PBC(I)	
1	-40.060	390.745	390.620	.12415	-39.850	386.023	386.211	-
2	-20.040	418.046	418.693	-.64673	-19.750	407.238	406.601	-
3	-.37000	434.472	433.312	1.16040	0.00000	419.654	420.214	-
4	14.7100	438.073	438.307	-.23431	15.0200	425.849	426.014	-
5	29.7000	438.365	439.171	-.80560	29.7900	427.988	427.737	-
6	44.6600	436.436	436.487	-.05164	45.0900	425.091	425.287	-
7	64.9900	428.007	427.055	-.95190	65.3300	416.069	415.419	-
8	84.7900	409.352	409.953	-.60059	85.2400	397.940	398.495	-
9	109.570	372.605	372.503	.10175	110.280	367.713	367.588	-

B-PROBE APPROXIMATION RESULTS : YAW0 = 28.8 PRESSURE (INCH H2O) =427.75

PSTATIC (DERIVED FROM PAMAX AND XVEL) = 402.086

POS#	Beta	Gamma	Xvel	Pitch	Yaw	BETA2
1	.08691	.30020	.15784	2.16	28.77	50.31

Table XII. Explicit Output of Reduced Data (run #119).

Raw Data From File AB1901:27.

POS#	Beta	Gamma	Xvel	Pitch	Yaw	BETA2
1	.08691	.30020	.15784	2.16	28.77	50.31
2	.08625	.29869	.15719	2.07	28.85	50.47
3	.08659	.29771	.15751	2.04	28.77	50.39
4	.08693	.29870	.15785	2.10	28.67	50.32
5	.08626	.29383	.15714	1.86	28.34	50.54
6	.08556	.29333	.15646	1.81	27.89	50.78
7	.08761	.29336	.15845	1.89	27.95	50.27
8	.08695	.29314	.15780	1.86	27.77	50.46
9	.08699	.30001	.15792	2.16	27.87	50.42
10	.08651	.29053	.15735	1.72	28.18	50.51
11	.08616	.30175	.15714	2.20	27.01	50.75
12	.08771	.30535	.15867	2.41	27.27	50.32
13	.08736	.31543	.15844	2.83	27.40	50.38
14	.08758	.31300	.15863	2.74	27.95	50.24
15	.08843	.31647	.15949	2.91	27.52	50.10
16	.08708	.32767	.15832	3.33	27.13	50.47
17	.08815	.33026	.15937	3.48	27.70	50.12
18	.08751	.33647	.15883	3.71	27.75	50.26
19	.08845	.34354	.15981	4.03	27.49	50.07
20	.08694	.35824	.15855	4.57	27.79	50.37
21	.08777	.35549	.15931	4.49	28.23	50.11
22	.08727	.35913	.15888	4.61	27.57	50.32
23	.08724	.36278	.15890	4.75	28.06	50.25
24	.08730	.36500	.15898	4.85	28.28	50.20
25	.08809	.35980	.15967	4.67	28.19	50.03
26	.08817	.35931	.15973	4.65	27.69	50.09
27	.08765	.36770	.15935	4.97	28.86	50.03
28	.08754	.37437	.15933	5.22	28.31	50.13
29	.08721	.35432	.15876	4.42	28.80	50.16
30	.08759	.36250	.15923	4.76	29.11	50.02
31	.08590	.34610	.15741	4.04	29.45	50.41
32	.08591	.33789	.15732	3.71	29.74	50.38
33	.08682	.34274	.15825	3.94	28.54	50.30
34	.08629	.33269	.15762	3.51	28.85	50.40
35	.08633	.33968	.15774	3.80	28.47	50.44
36	.08652	.33720	.15789	3.70	29.09	50.31
37	.08466	.32843	.15600	3.27	28.94	50.81
38	.08430	.32945	.15566	3.29	28.62	50.94
39	.08466	.31729	.15586	3.00	28.75	50.85
40	.08445	.31319	.15561	2.62	29.15	50.86
41	.08548	.31905	.15668	2.91	28.62	50.66
42	.08583	.32284	.15706	3.08	27.88	50.67
43	.08569	.31942	.15688	2.93	28.83	50.58
44	.08616	.31527	.15729	2.78	28.39	50.53
45	.08673	.32951	.15801	3.39	29.01	50.28
46	.08768	.32712	.15888	3.33	28.90	50.06
47	.08778	.32402	.15894	3.21	28.34	50.12
48	.08757	.32691	.15878	3.32	29.08	50.07
49	.08892	.31918	.15998	3.04	28.51	49.82
50	.08780	.32379	.15897	3.20	28.24	50.13
51	.08746	.32749	.15868	3.34	28.18	50.22
52	.08814	.31063	.15914	2.65	28.43	50.04

Table XIII. Reduced Data For the First Blade Passage of Run #119.

Range of Xvel	Range of Pitch	Range of Yaw	$E_x [\%]$	$E_\phi [^\circ]$	$E_\alpha [^\circ]$
$0.134 \leq X \leq 0.216$	$0 \leq \phi \leq 10$	$-10 \leq \alpha \leq 10$	-4.6	0.78	-0.93
$0.134 \leq X \leq 0.216$	$5 \leq \phi \leq 15$	$-10 \leq \alpha \leq 10$	-4.7	0.96	-0.77
$0.175 \leq X \leq 0.263$	$0 \leq \phi \leq 10$	$-10 \leq \alpha \leq 10$	6.0	0.50	-0.65
$0.175 \leq X \leq 0.263$	$5 \leq \phi \leq 15$	$-10 \leq \alpha \leq 10$	-5.0	0.66	-0.57

Table XIV. Errors in Mach Number, Pitch and Yaw Angle for Varying Velocity Vectors.

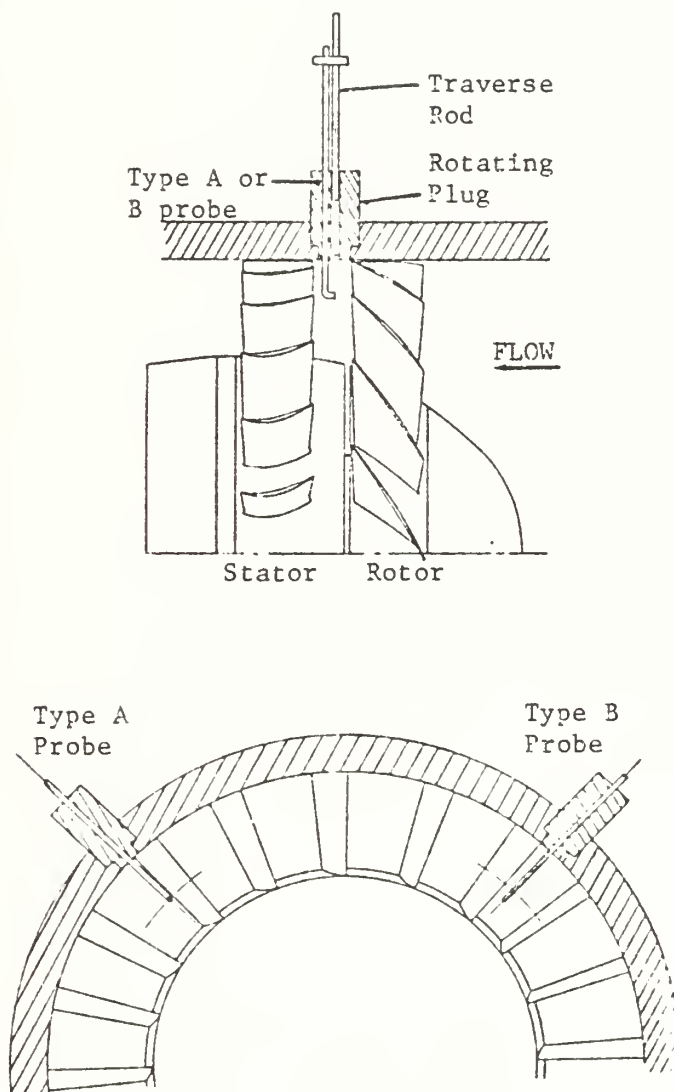


Figure 1. Probe Arrangement in Transonic Compressor

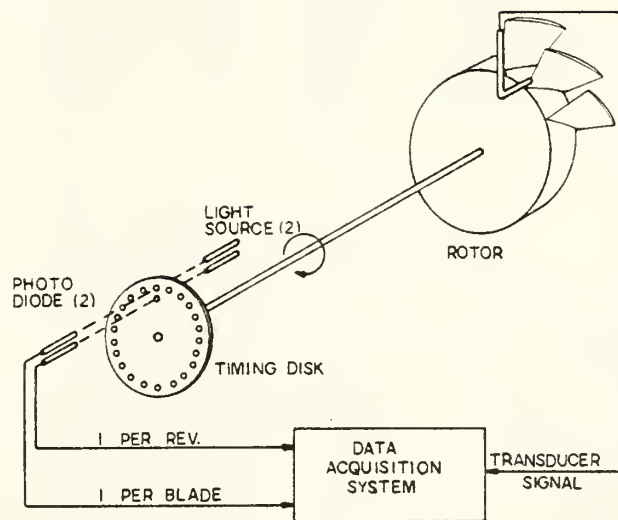


Figure 2. Controlled (Paced) Sampling Technique

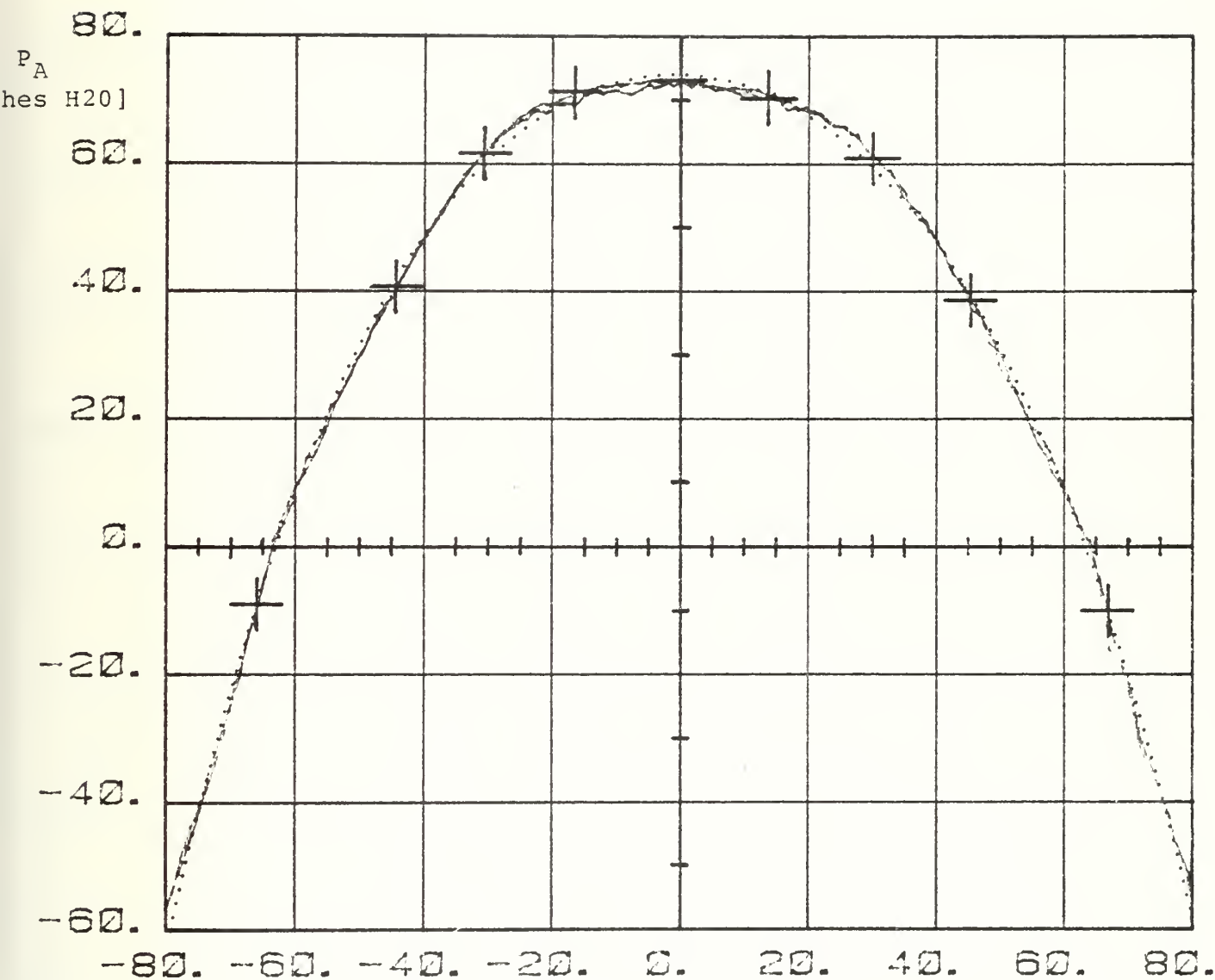


Figure 3a. A-Probe Pressure (Gauge) vs. Yaw Angle YAW ANGLE [Degrees]
 Solid line - Calibration Data
 Dotted line - Data Approximated from Specific Data Points
 (4th Order Polynomials) Shown as crosses
 (Datafile: A5KP10)

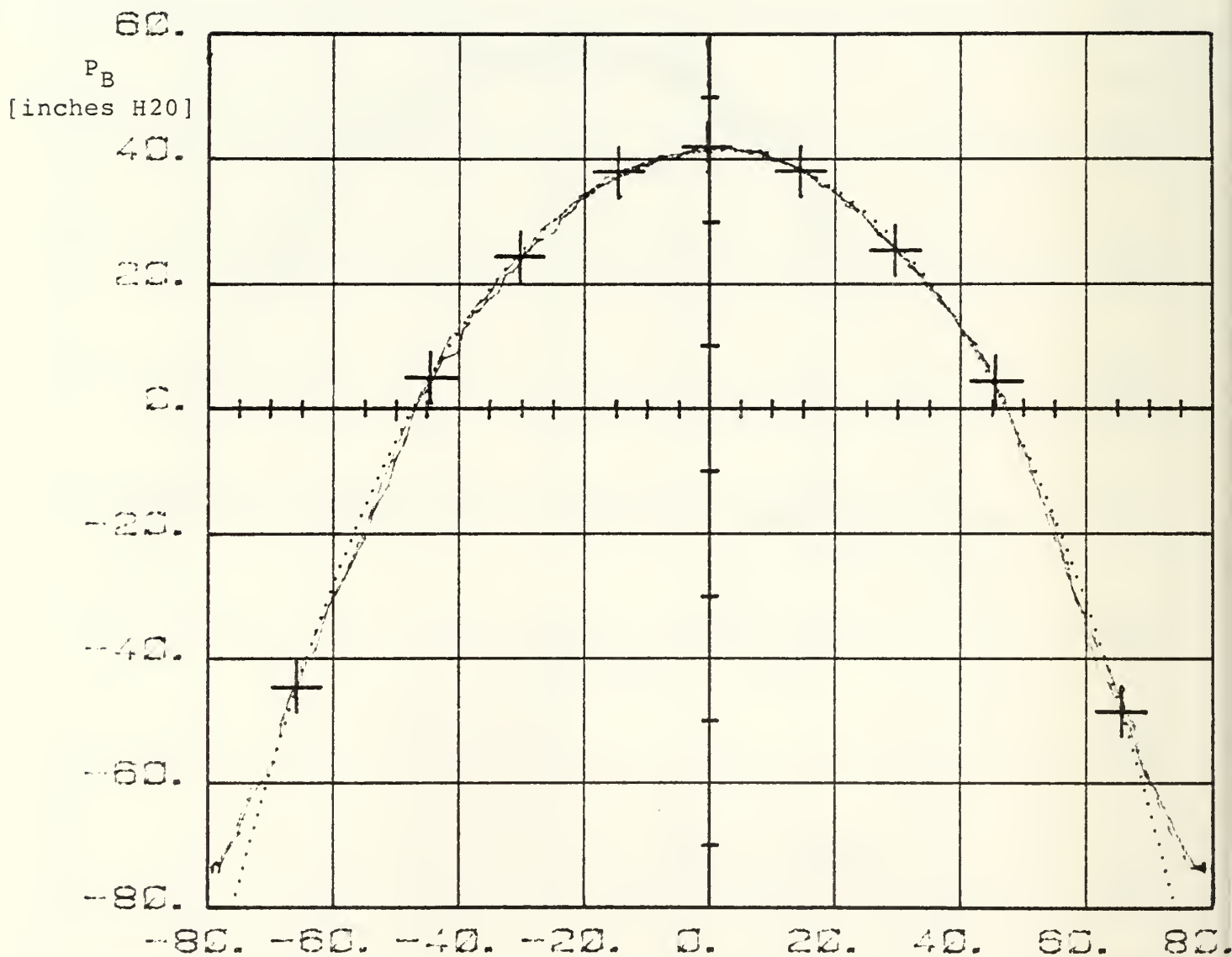


Figure 3b. B-Probe Pressure (Gauge) vs. Yaw Angle YAW ANGLE [Degree]
 Solid line - Calibration Data
 Dotted line - Data Approximated from Specific Data Points
 (4th Order Polynomials) Shown as crosses
 (Datafile: B5KP10)

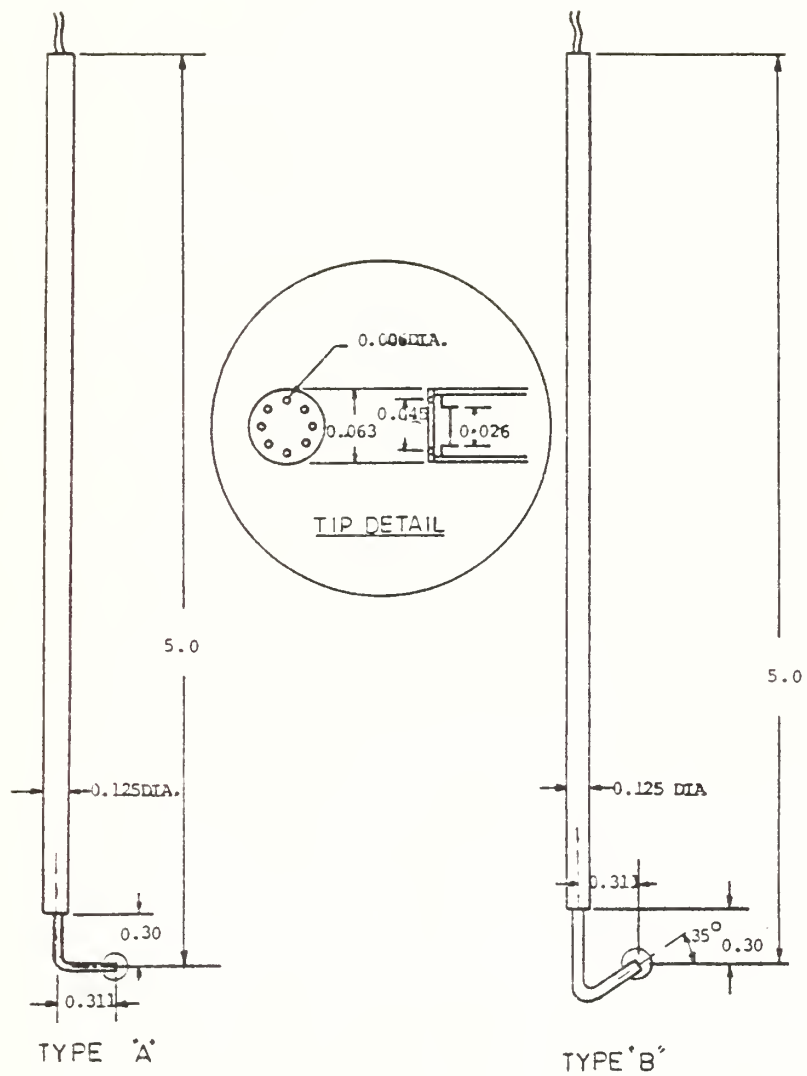


Figure 4. High Response Transducer Probes

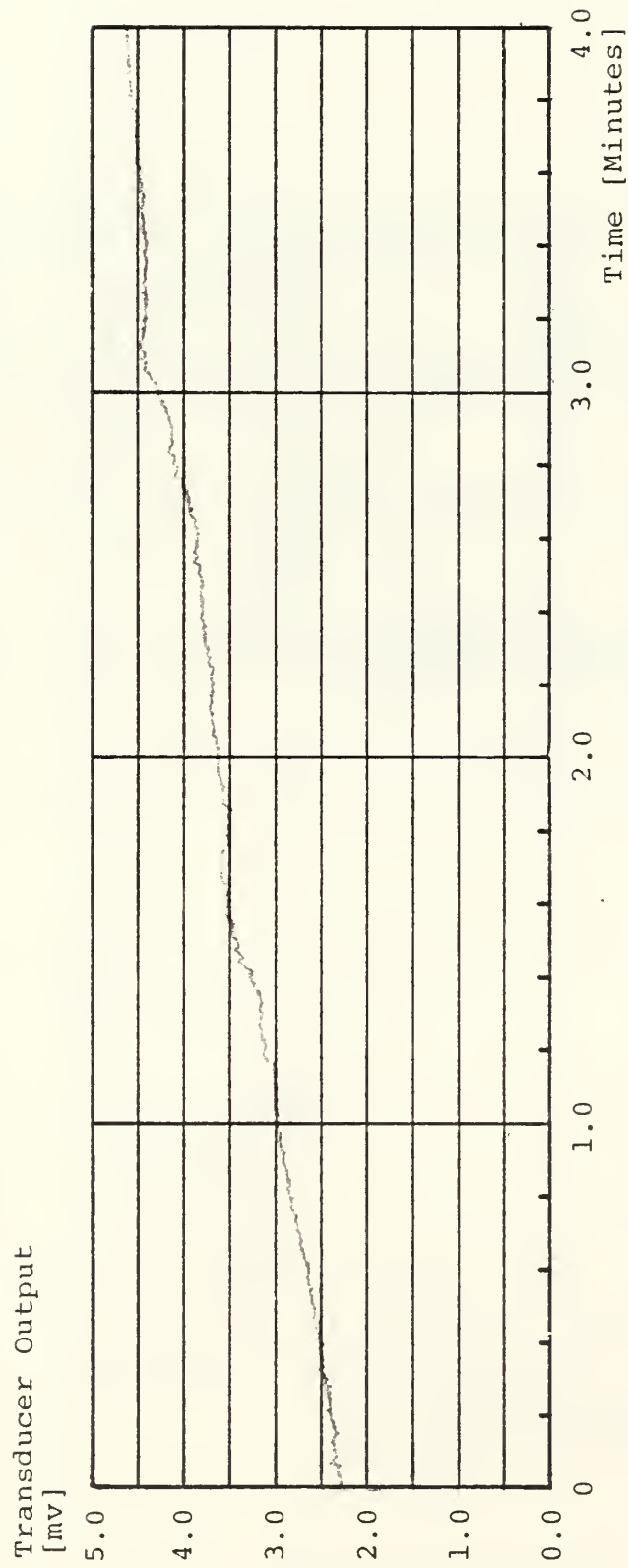


Figure 5. Temperature Sensitivity of a Kulite-Transducer
Calibrated to: 1mv Equivalent to 1 Inch of Water (Gauge)
4 Minutes Equivalent to 1000 Single Samples

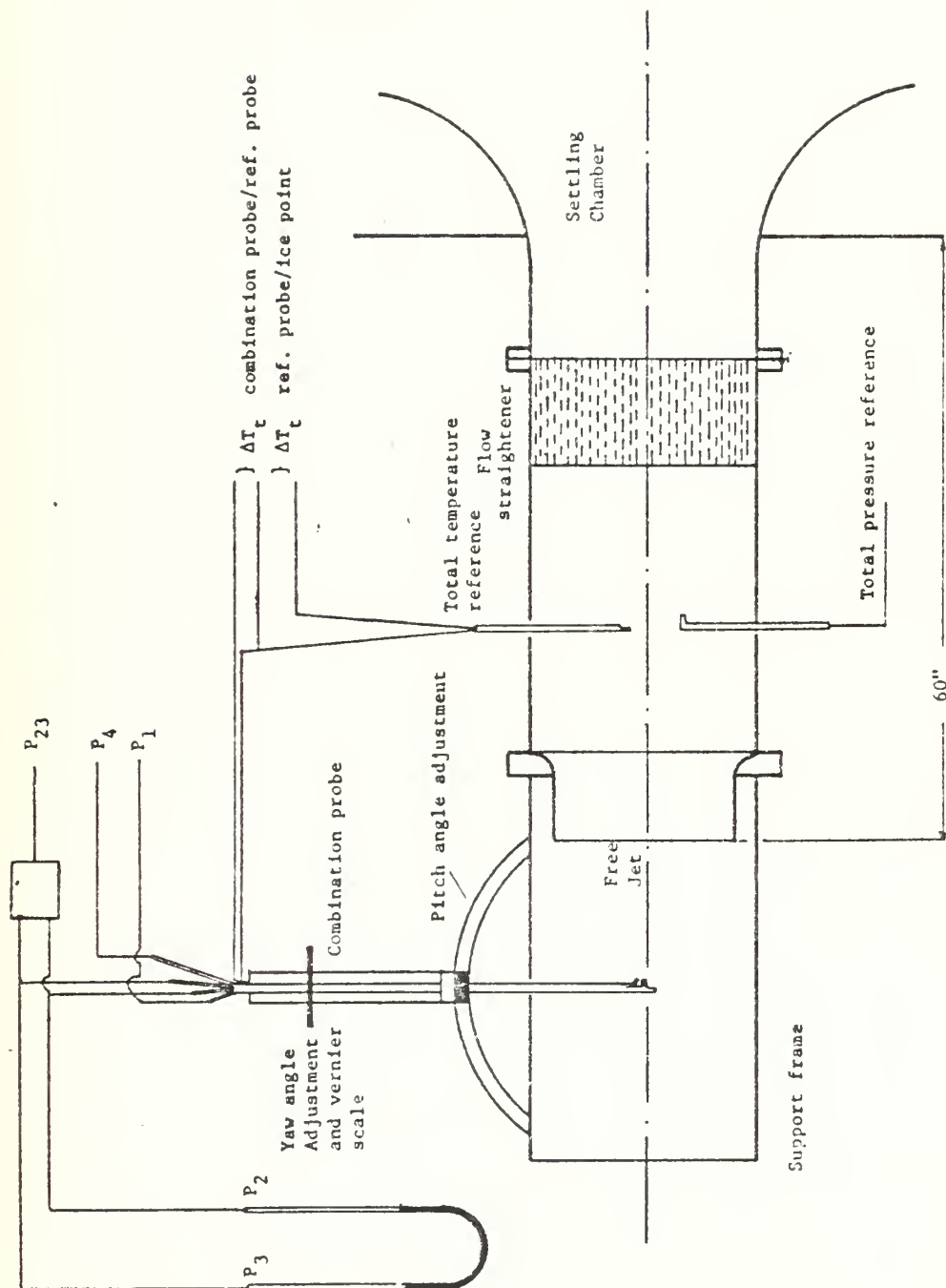
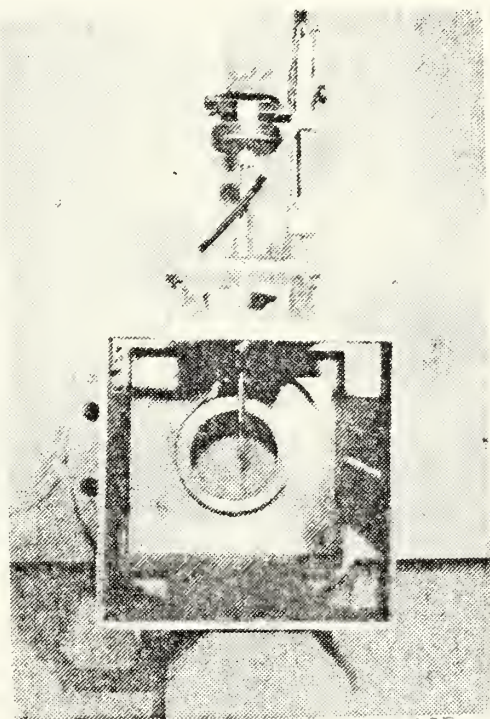
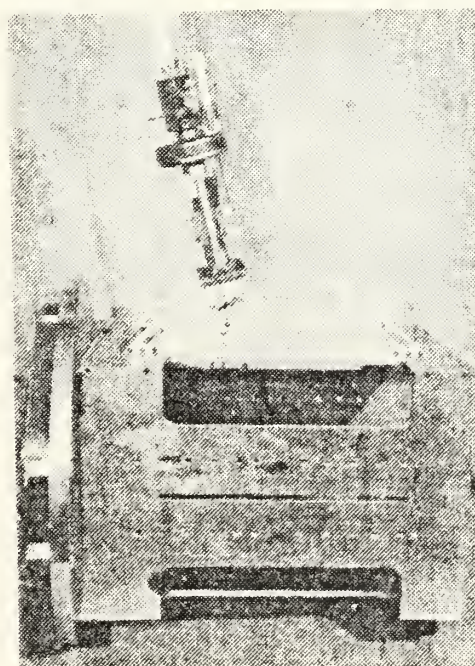


Figure 6a. Calibration Facility Geometry (not to scale)



(a) End View



(b) Side View

Figure 6b. Free-Jet Calibration Apparatus

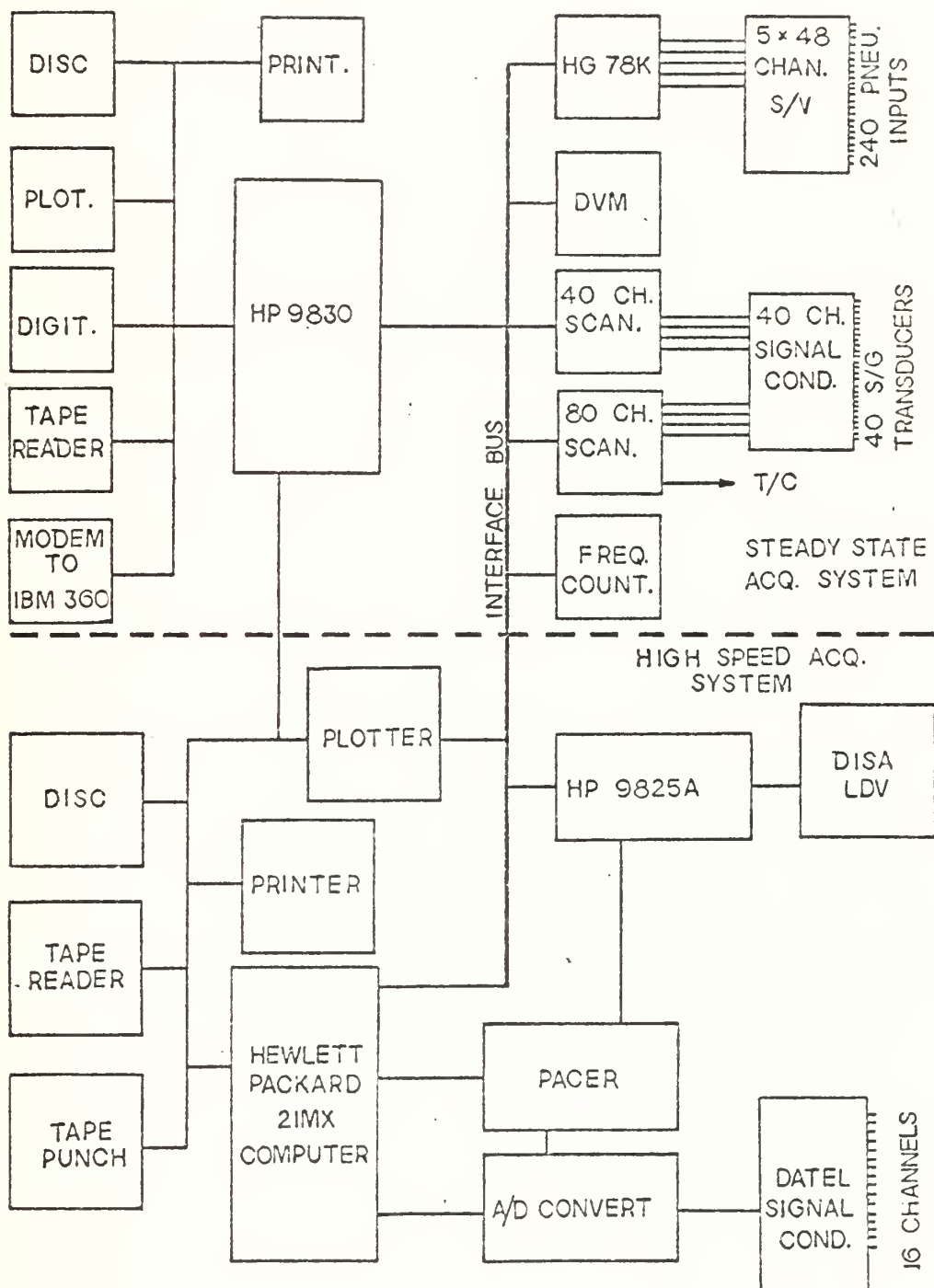


Figure 6c. Data Acquisition System

P_A
[inches H2O Gauge]

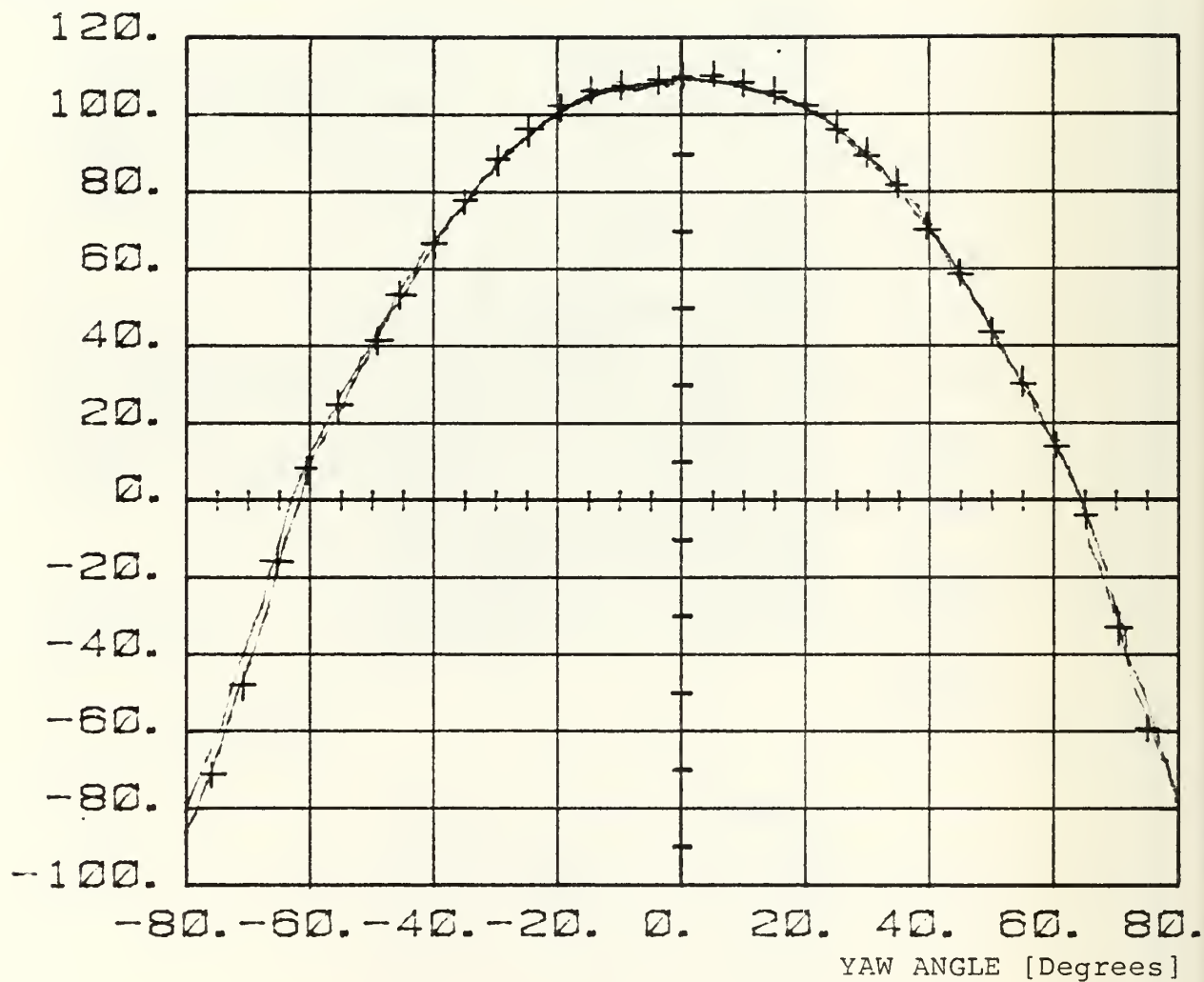


Figure 7. Pressure Readings vs. Yaw Angle. Data Acquired Using Two Different Programs:
Solid lines - Program KALIB (Continuous Acquisition)
Crosses - Program &YAW (Discrete Readings)

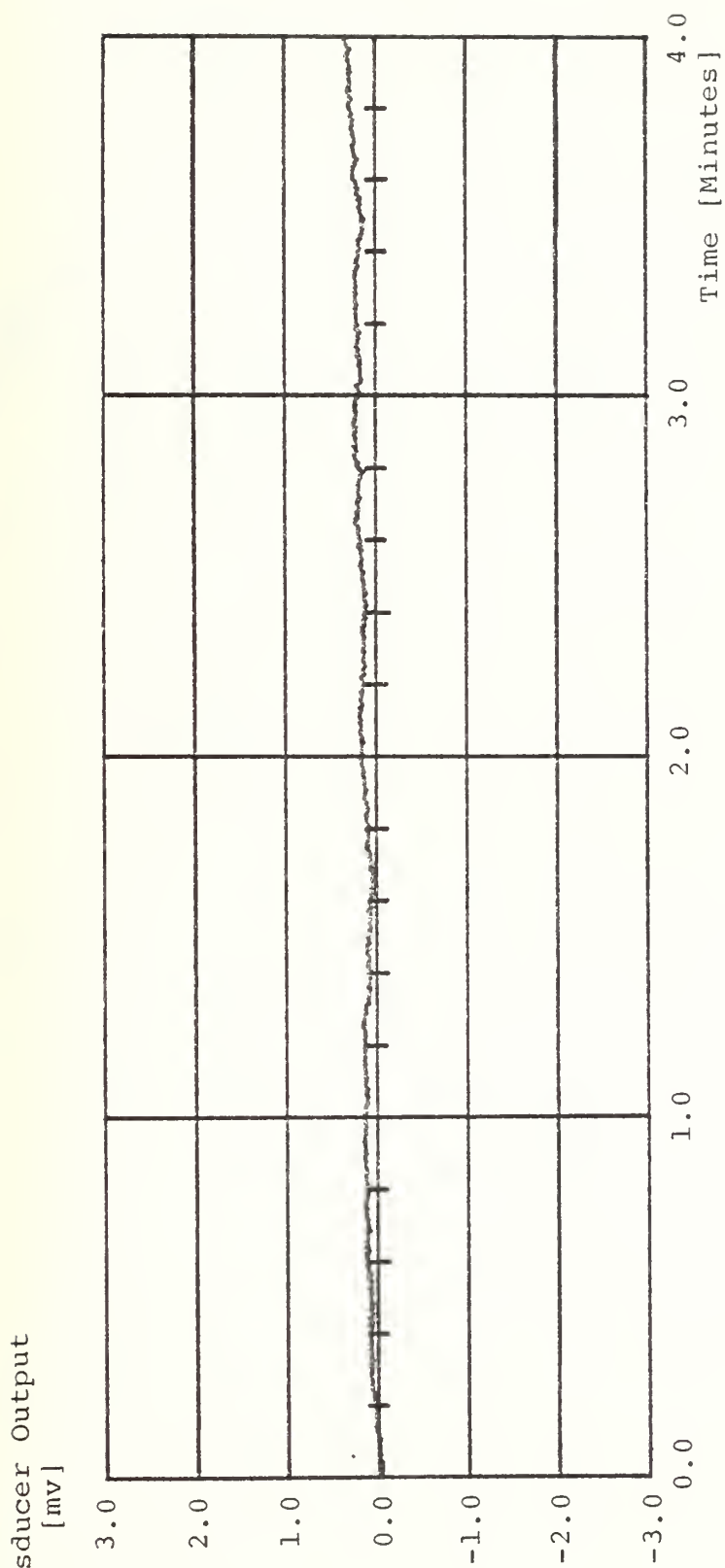


Figure 8. Kulite Transducer Output Depending on Time, No Change in Environment. Calibrated to: 1mv Equivalent to 1 inch of Water.

P_A
[inches H₂O Gauge]

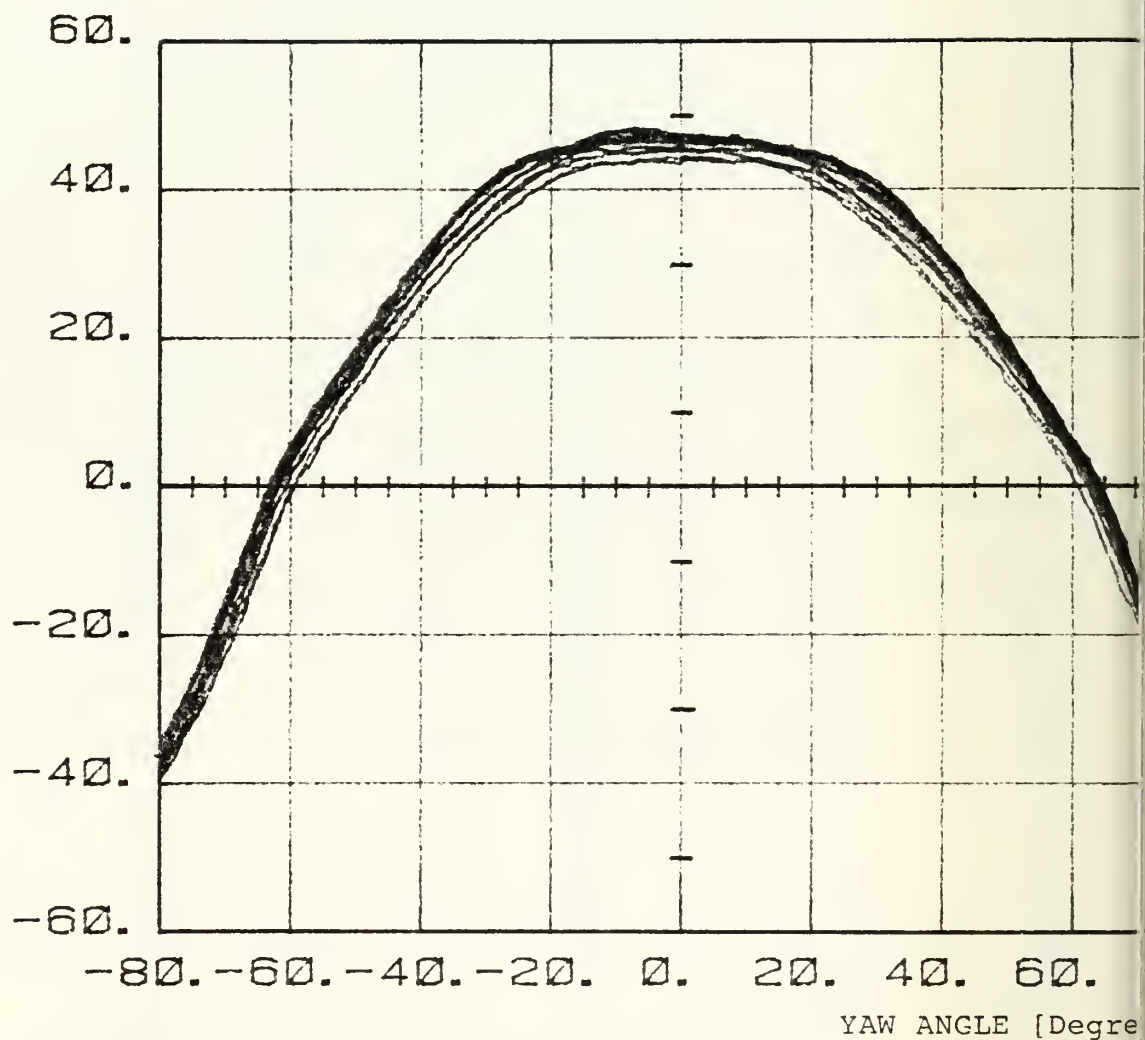


Figure 9. Type A-Probe Calibration Data at Mach = 0.4. Pitch Angles in the Range from -15° to $+25^\circ$

P_A
[inches H2O Gauge]

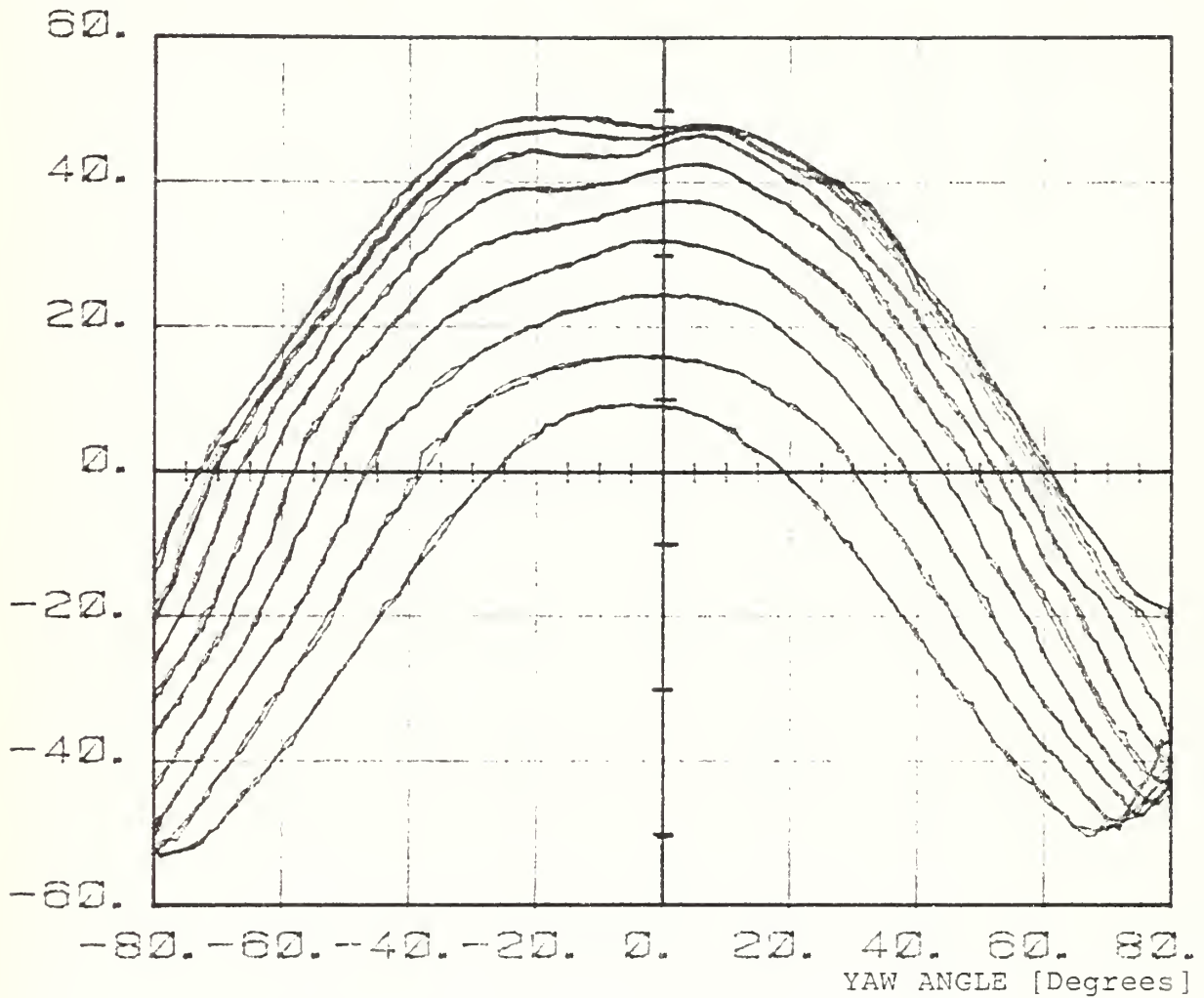


Figure 10. Type B-Probe Calibration Data at Mach = 0.4. Pitch angles in the Range from -15° (Top) to $+25^\circ$ in 5° Increments. Some Holes in probe tip are contaminated by dirt.



Figure 11a. Probe Tip with Dirt in Some Holes

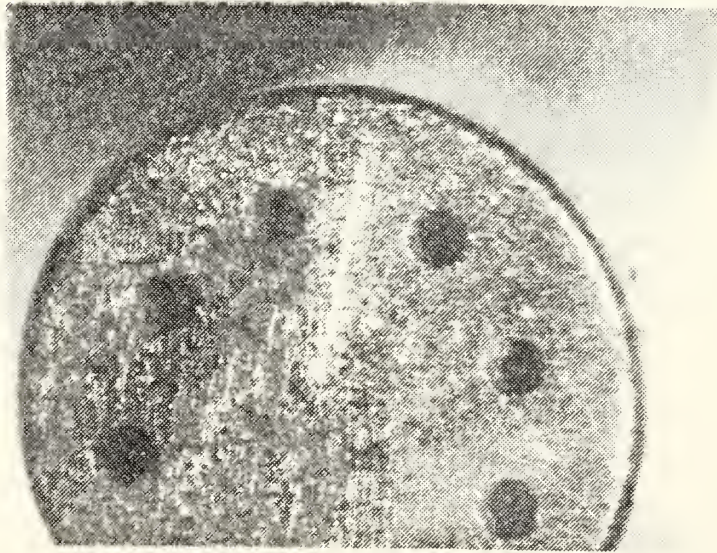


Figure 11b. Probe Tip with Dirt in Some Holes

P_A
[inches H₂O Gauge]

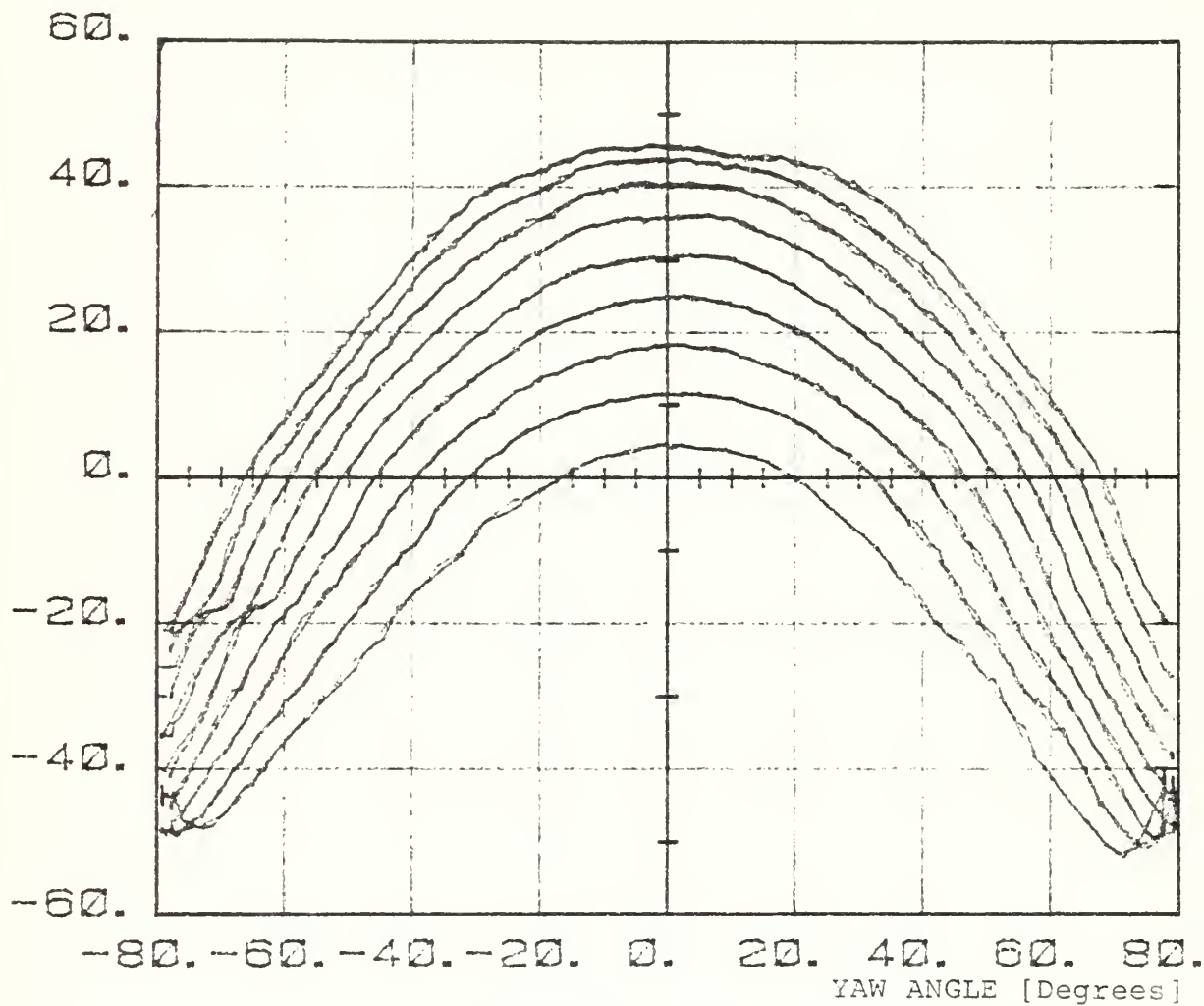


Figure 12. Type B-Probe Calibration Data at Mach = 0.4.
Pitch angles in the Range from -15° (Top) to
+25° in 5° Increments. Clean Probe Tip.

P_A
[inches H2O Gauge]

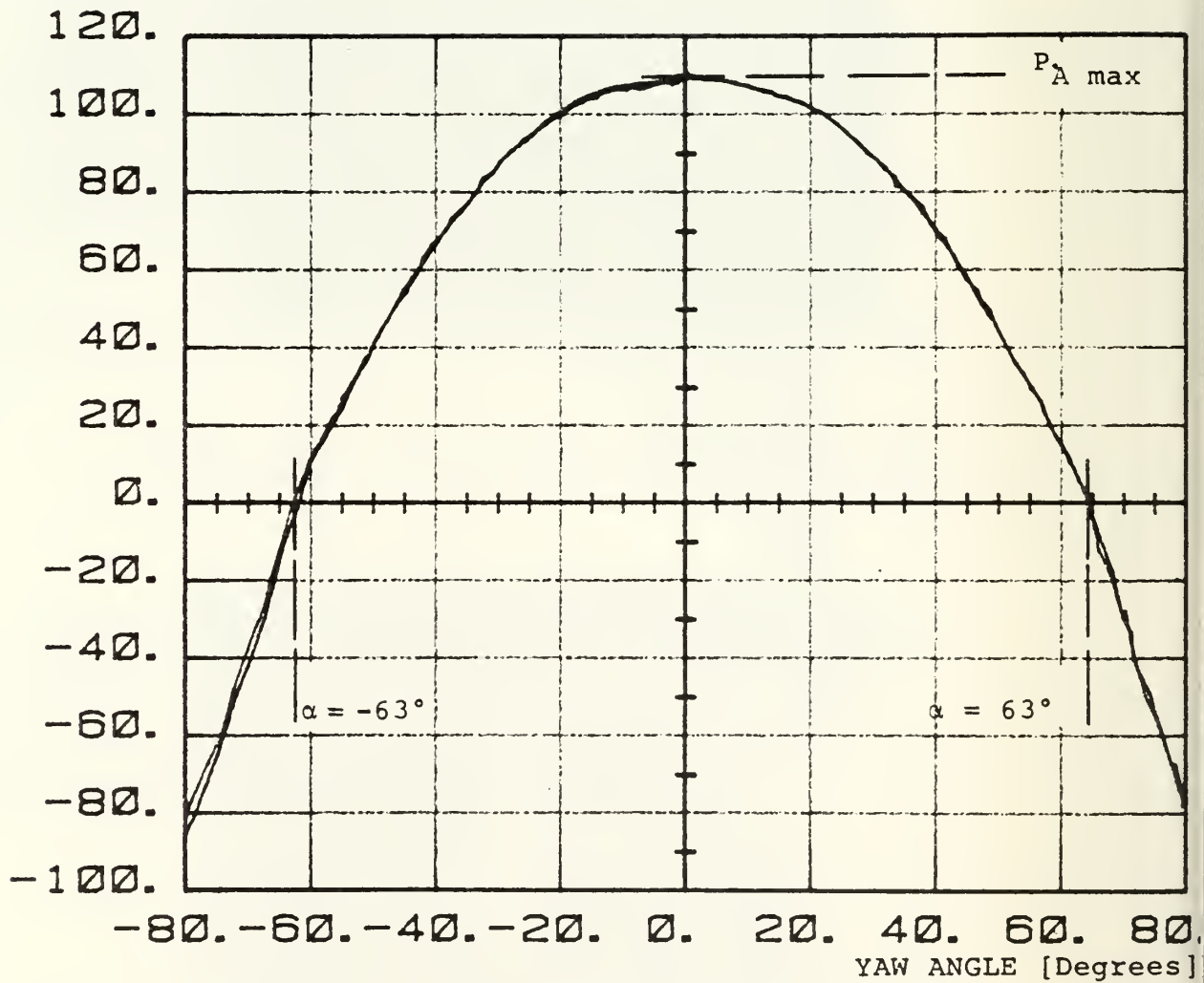


Figure 13. Type A-Probe Output Demonstrating Characteristic Values.
(Mach = 0.6, Pitch angle = 25°)

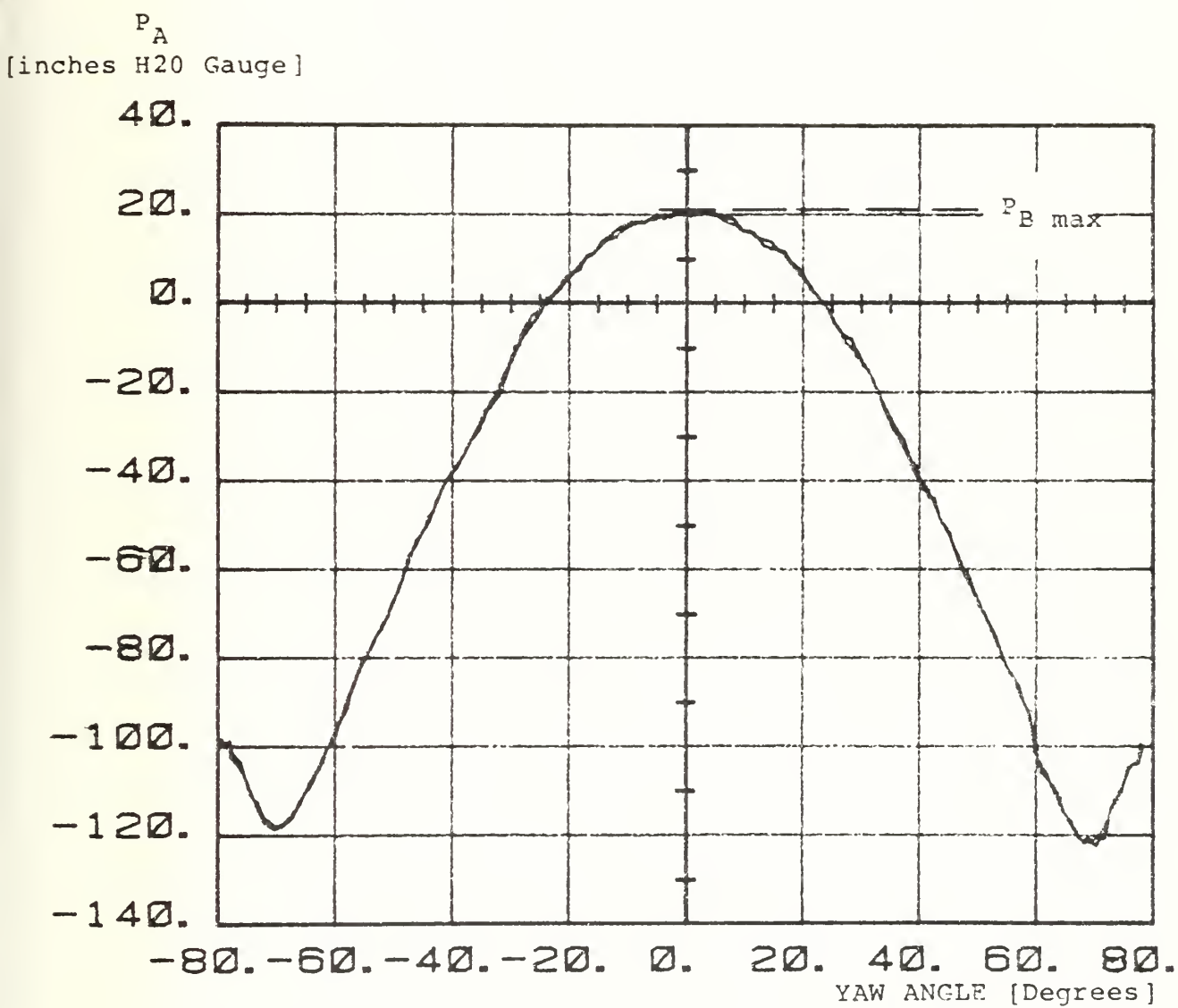


Figure 14. Type B-Probe Calibration Data
(Mach = 0.6, Pitch angle = 25°)

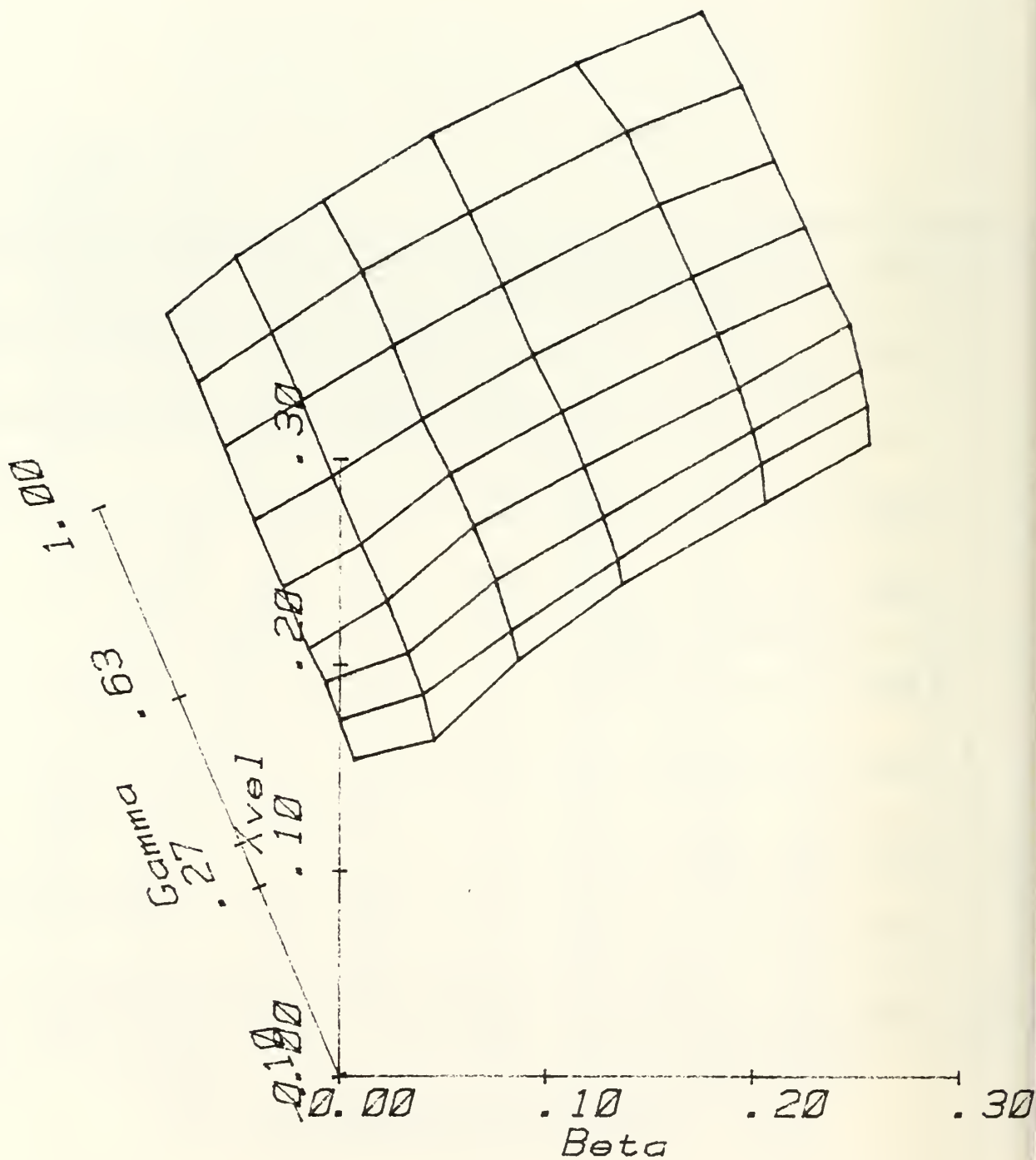


Figure 15a. Approximation of Dimensionless Velocity, X , as Function of Coefficients β and γ .

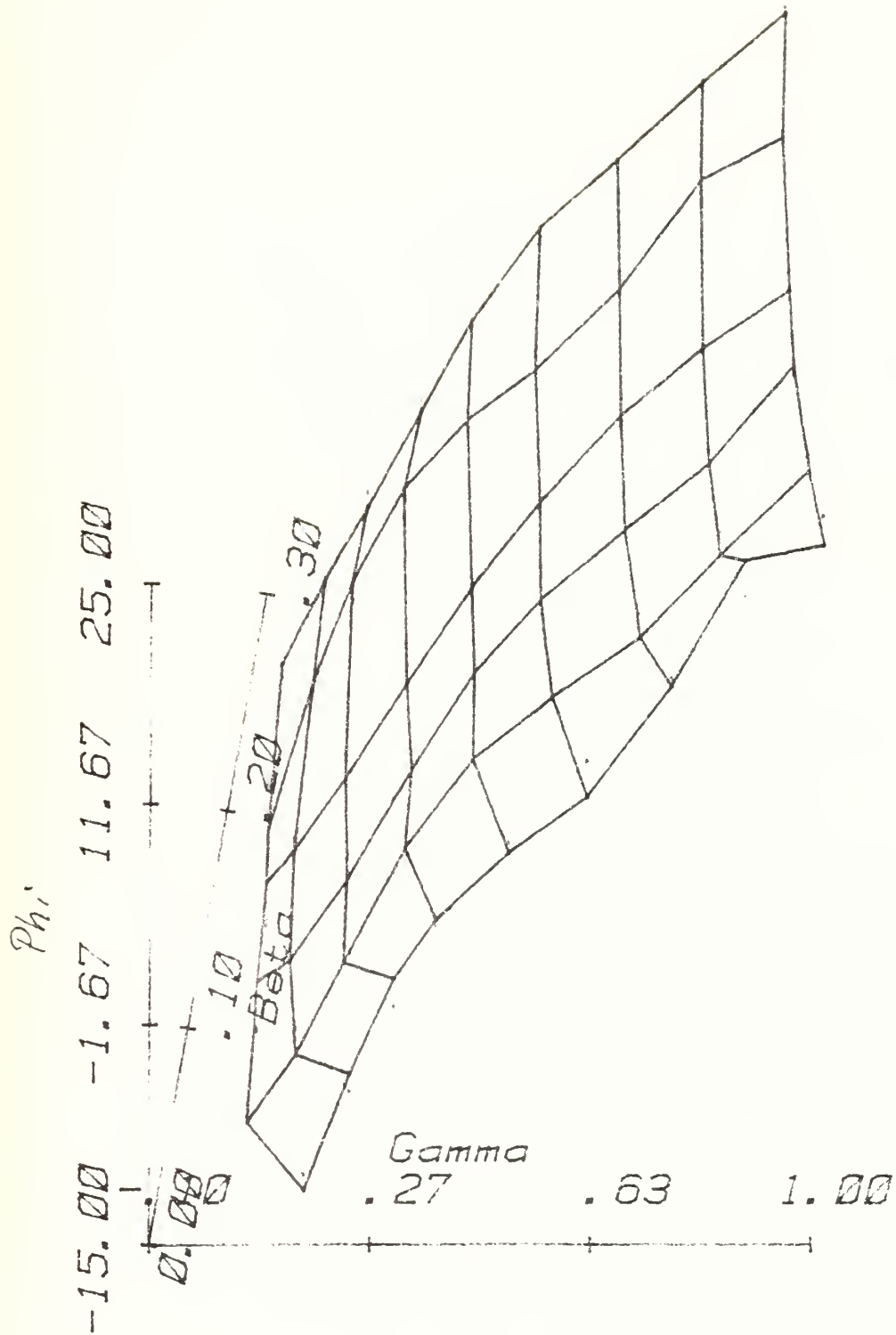


Figure 15b. Approximation of Pitch angle ϕ as Function of Coefficients β and γ .

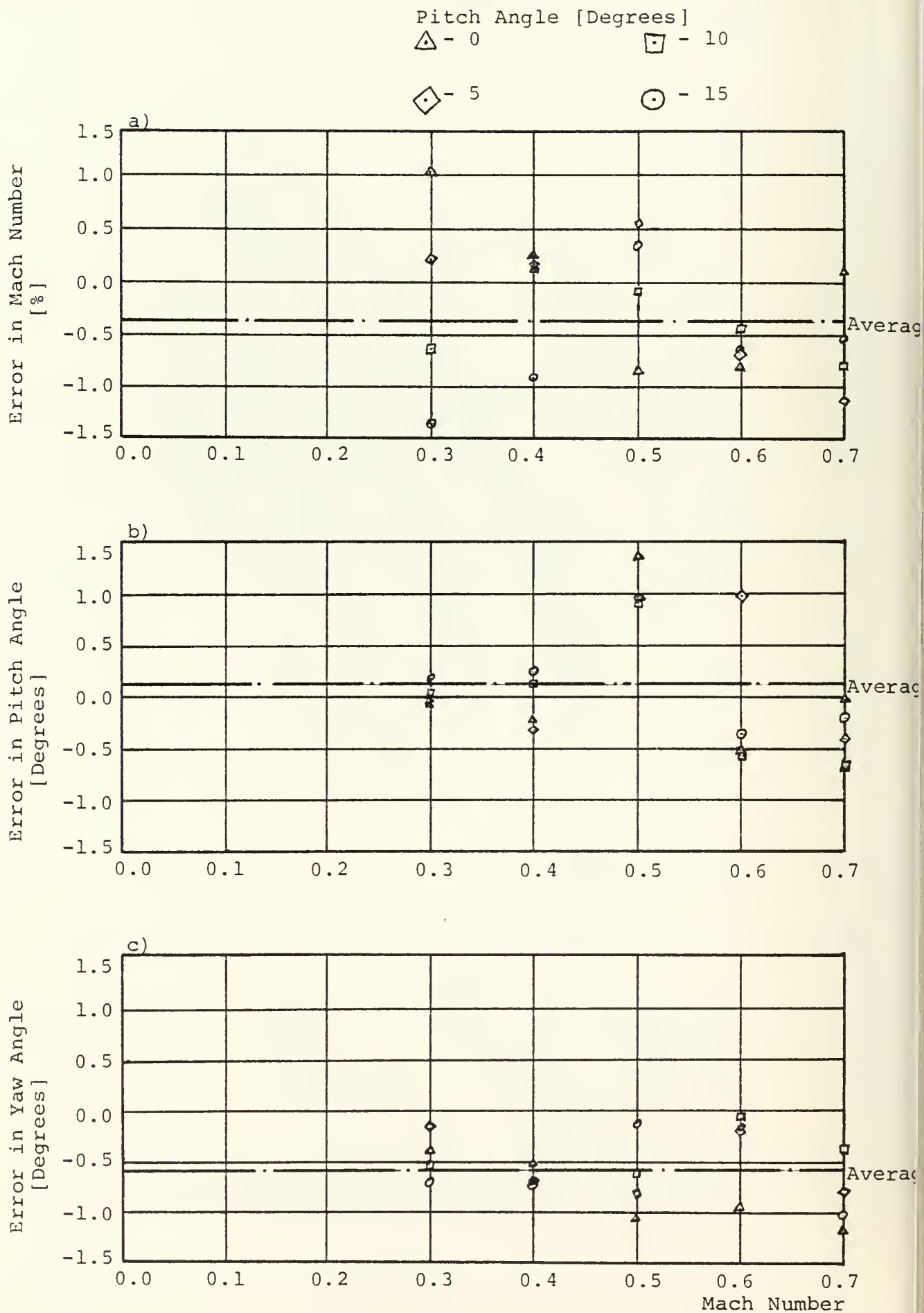


Figure 16. Errors as Specified Depending on Mach Number and Pitch Angle.

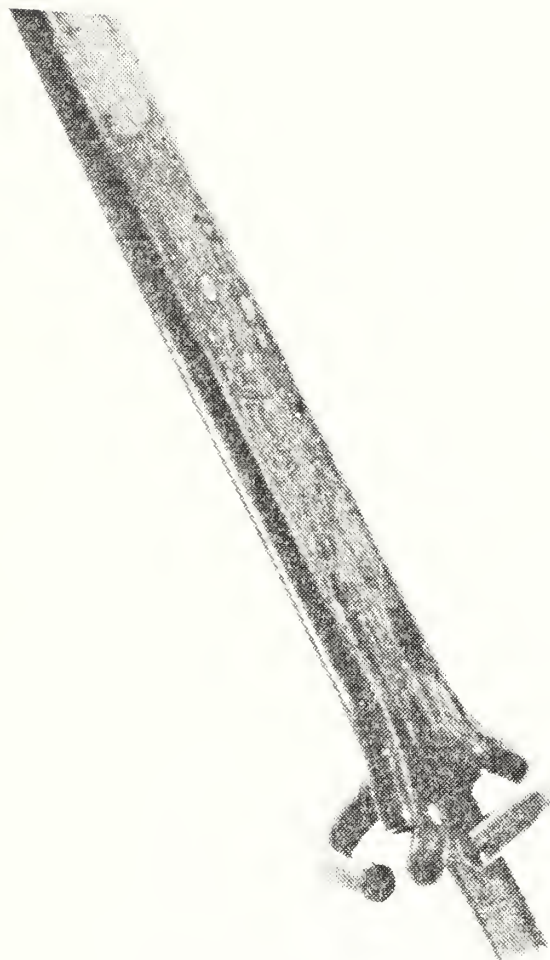


Figure 17. Combination Pressure Temperature Probe
(Tip Detail)

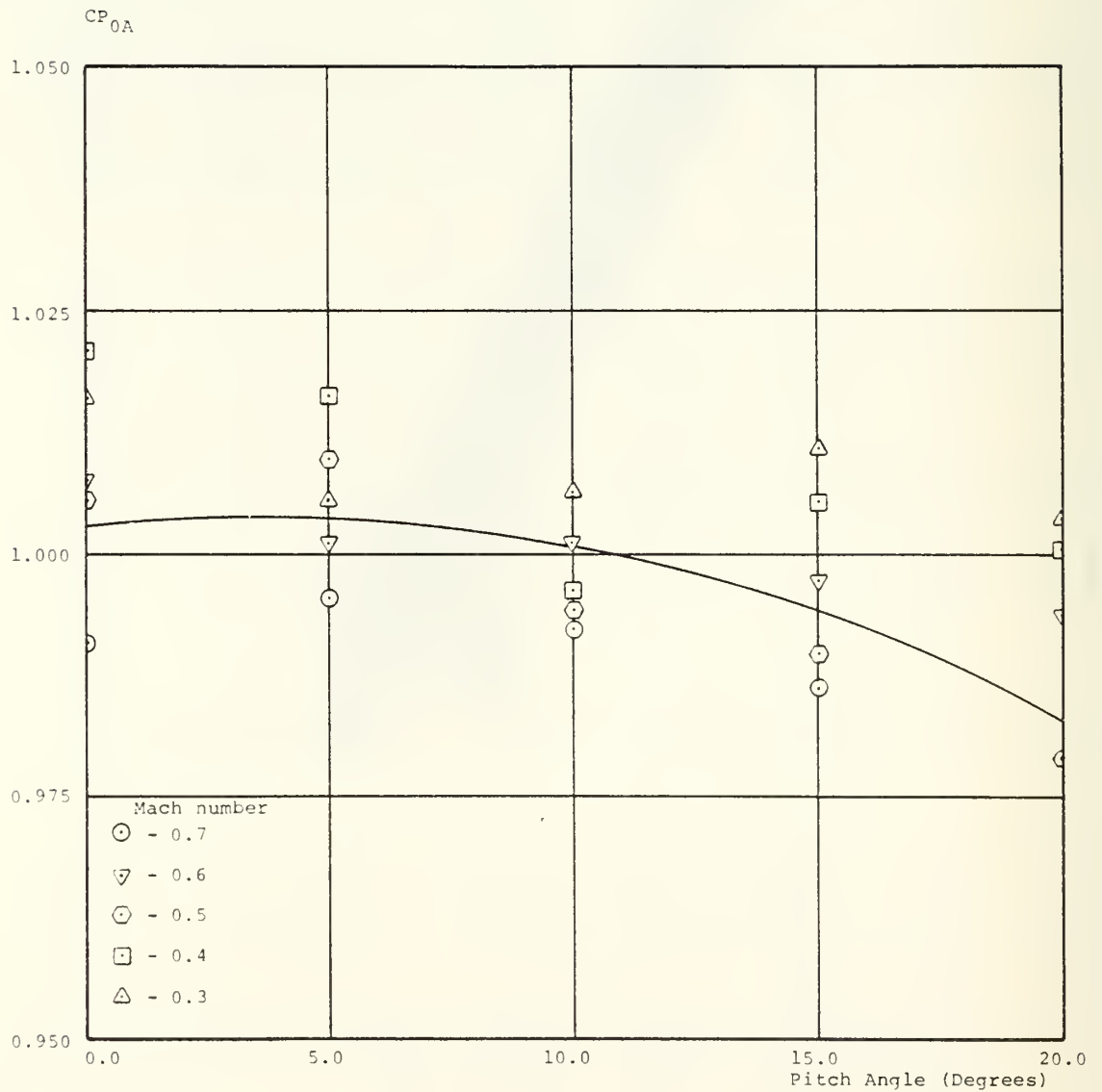


Figure 18. Pressure Coefficient for Type A-Probe at Zero Yaw Angle as Function of Mach Number and Pitch Angle.

CP_{OB}

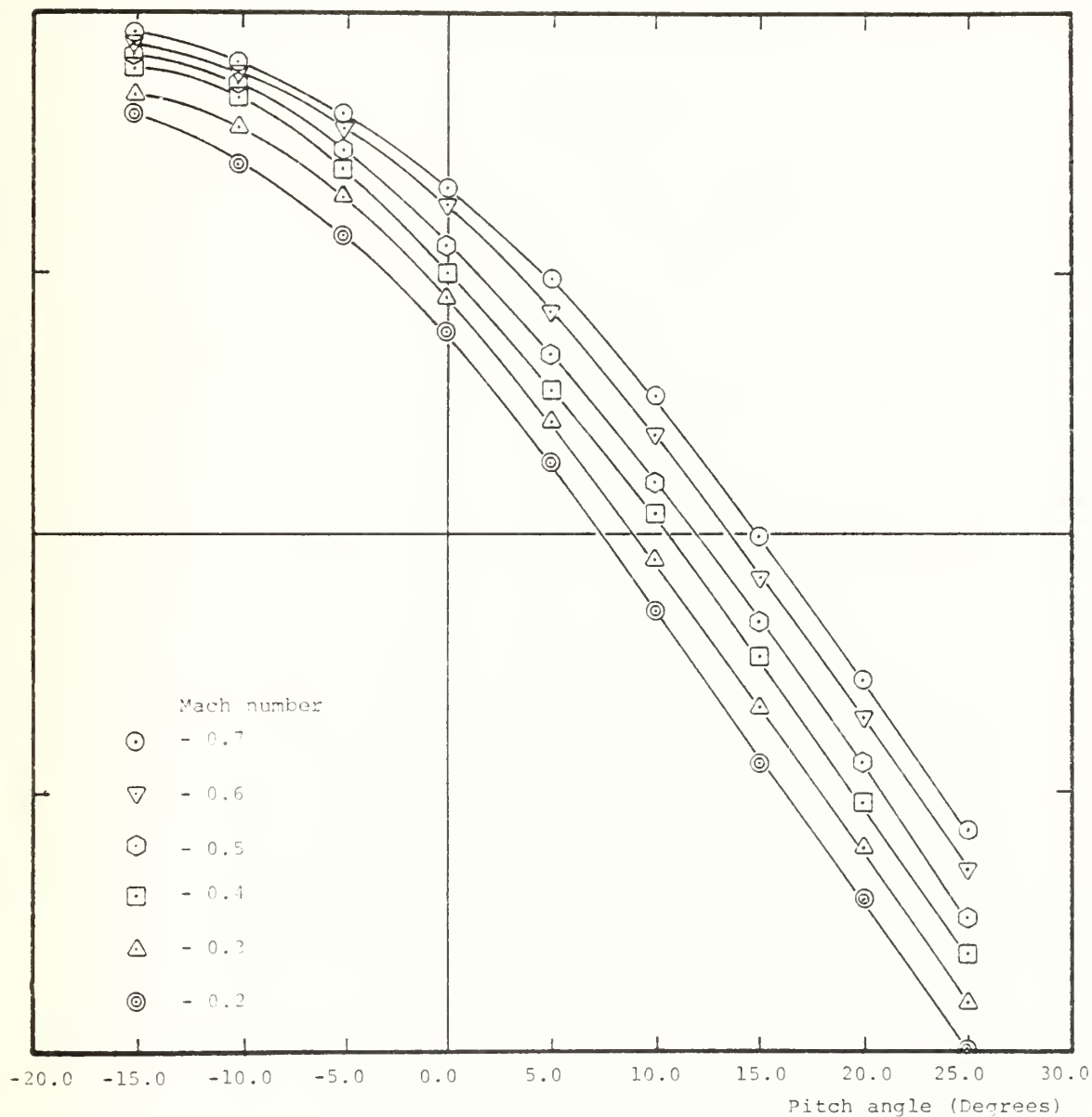
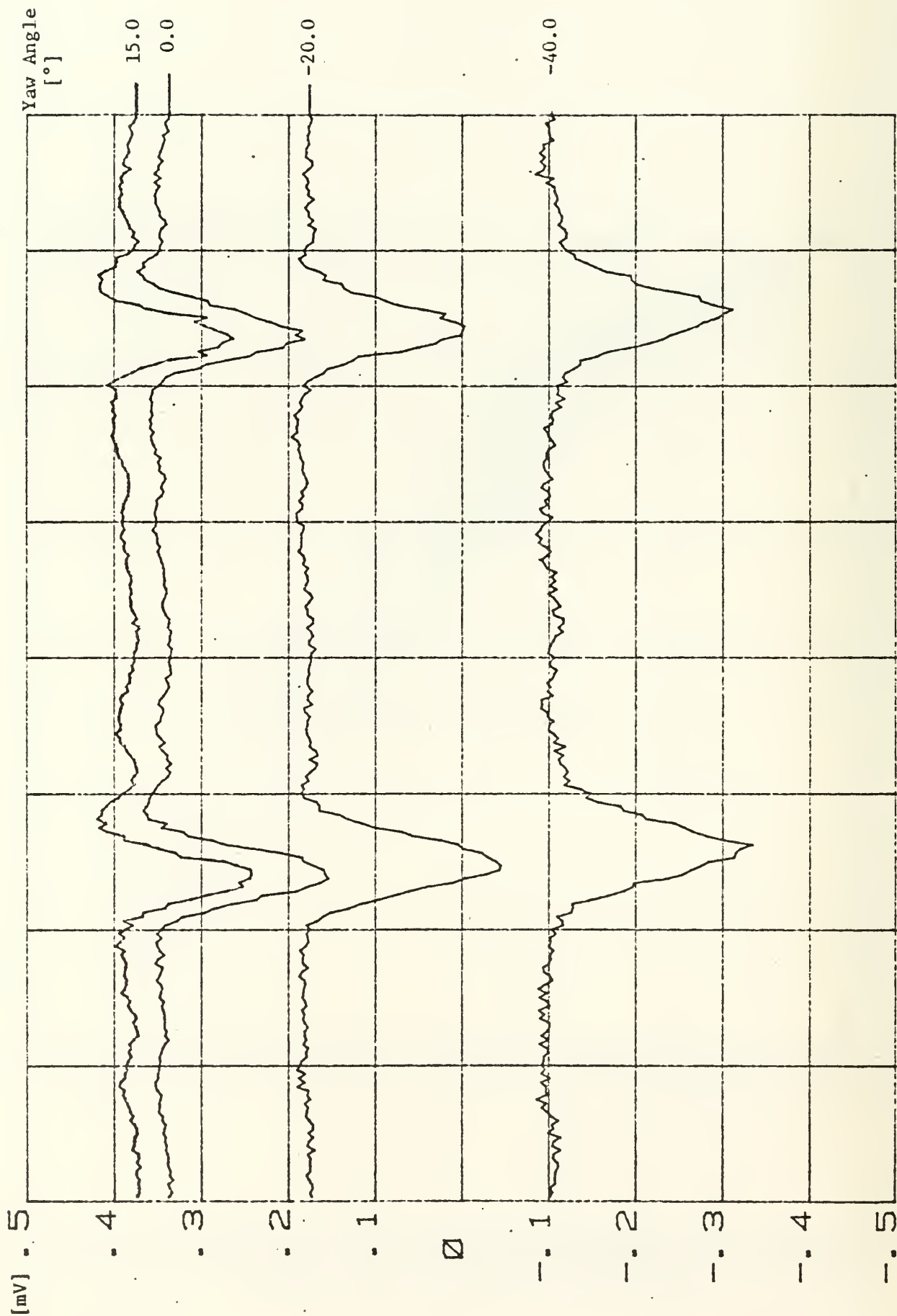


Figure 19. Pressure Coefficient for Type B-Probe for Zero Yaw Angle as Function of Mach Number and Pitch Angle.

A-probe raw data

File: AB19A1



0.0 32.0 64.0 96.0 128.0 160.0 192.0 224.0 256.0

Position

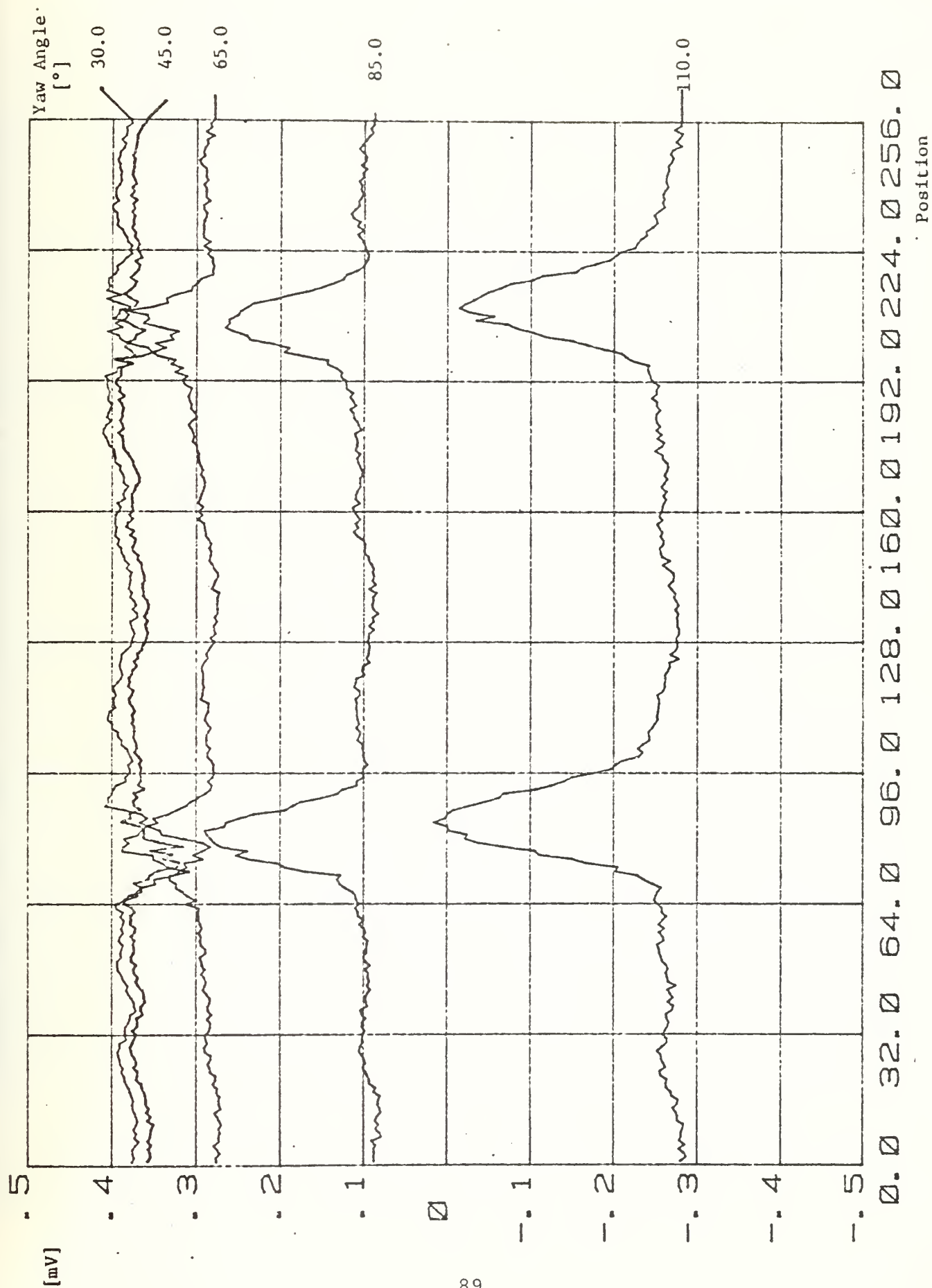
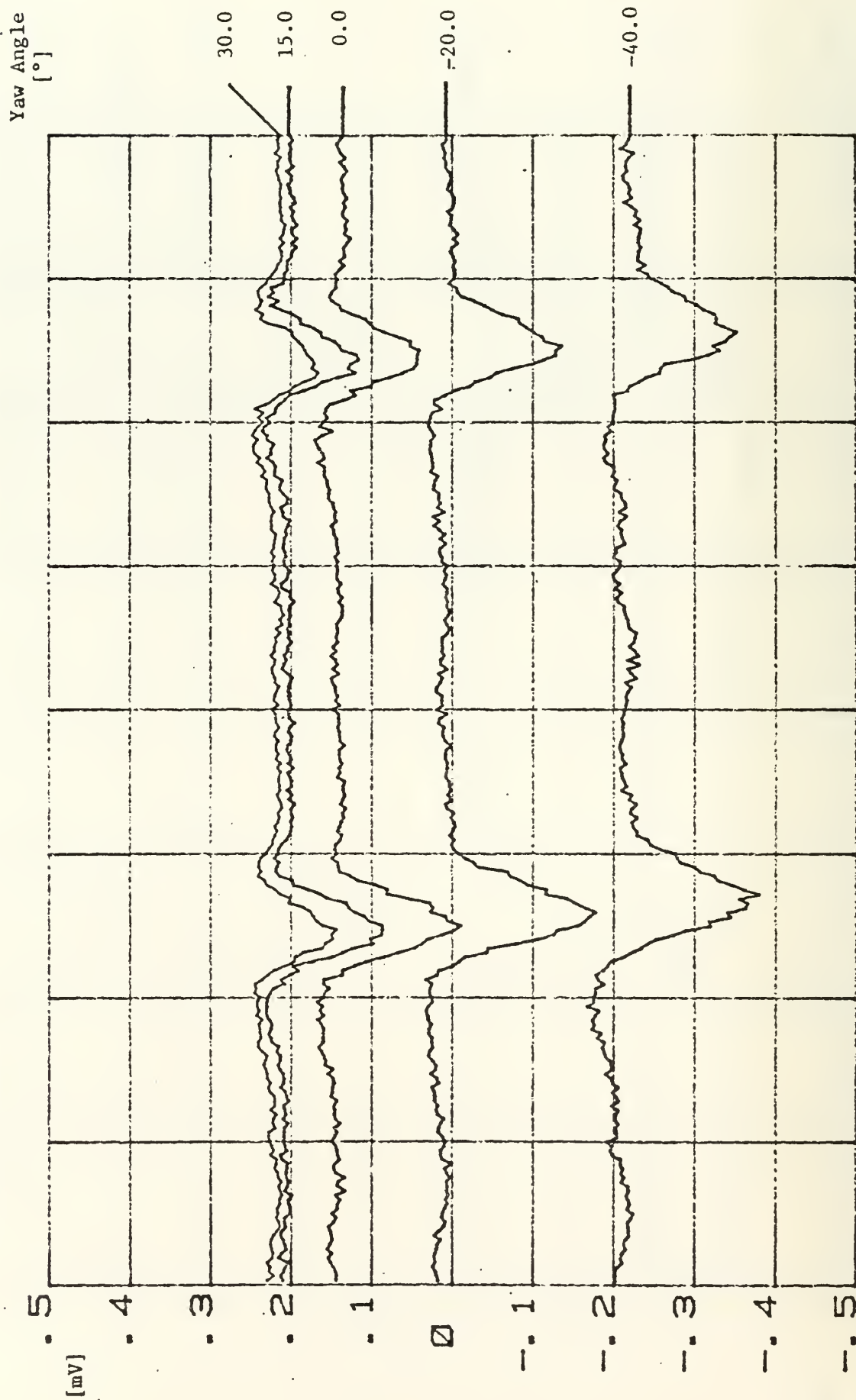


Figure 20b. Paced Data From Type A Probe. Probe Yaw Angle Settings as Indicated.

B-probe raw data

File: AB19B1



B-probe raw data

File: AB19B1

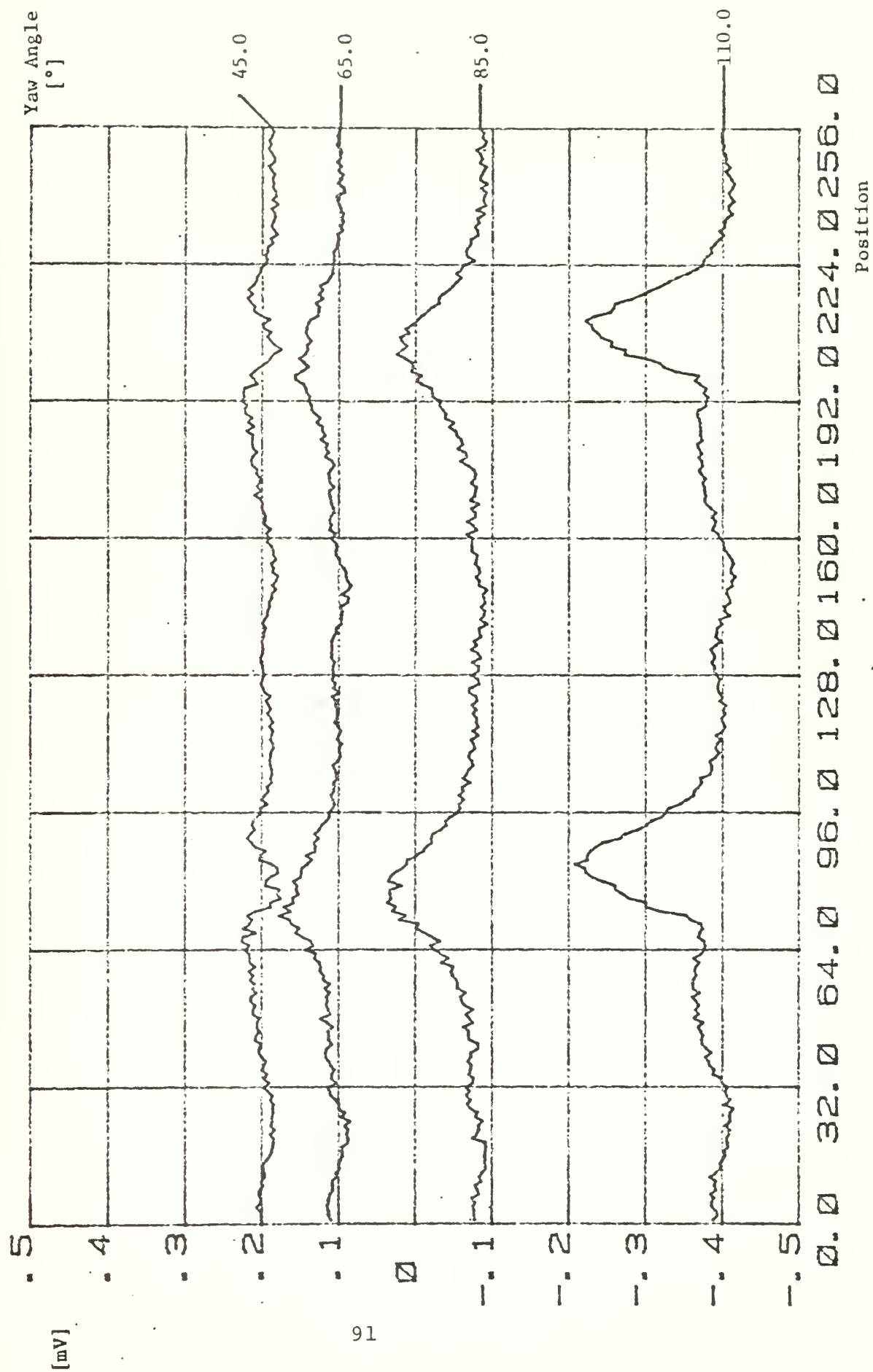


Figure 20d. Paced Data from Type B-Probe
Probe Yaw Angle Settings as Indicated.

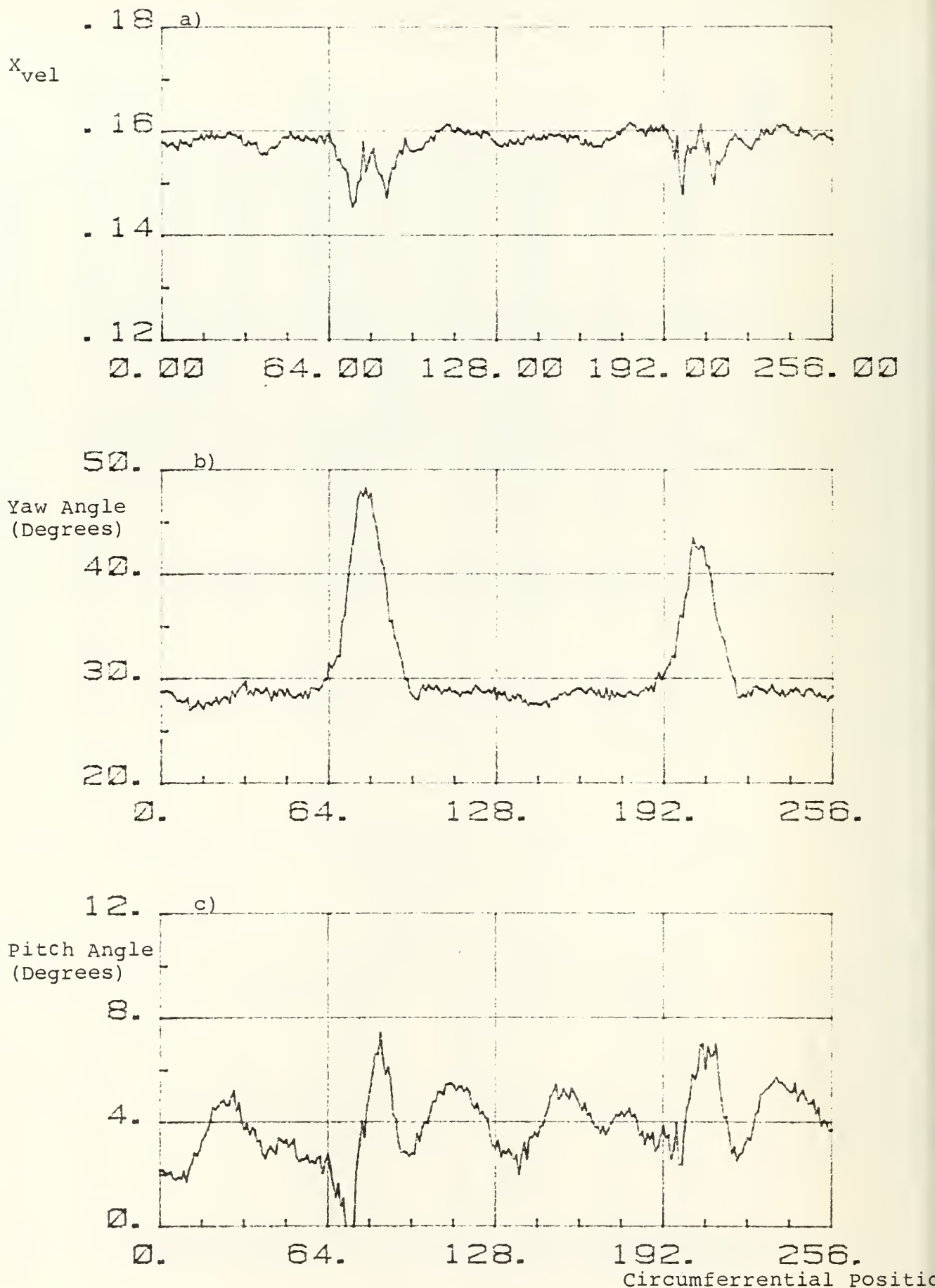


Figure 21. Measurement Results at 50% Speed, Midspan, Peak Efficiency (File AB19R1).

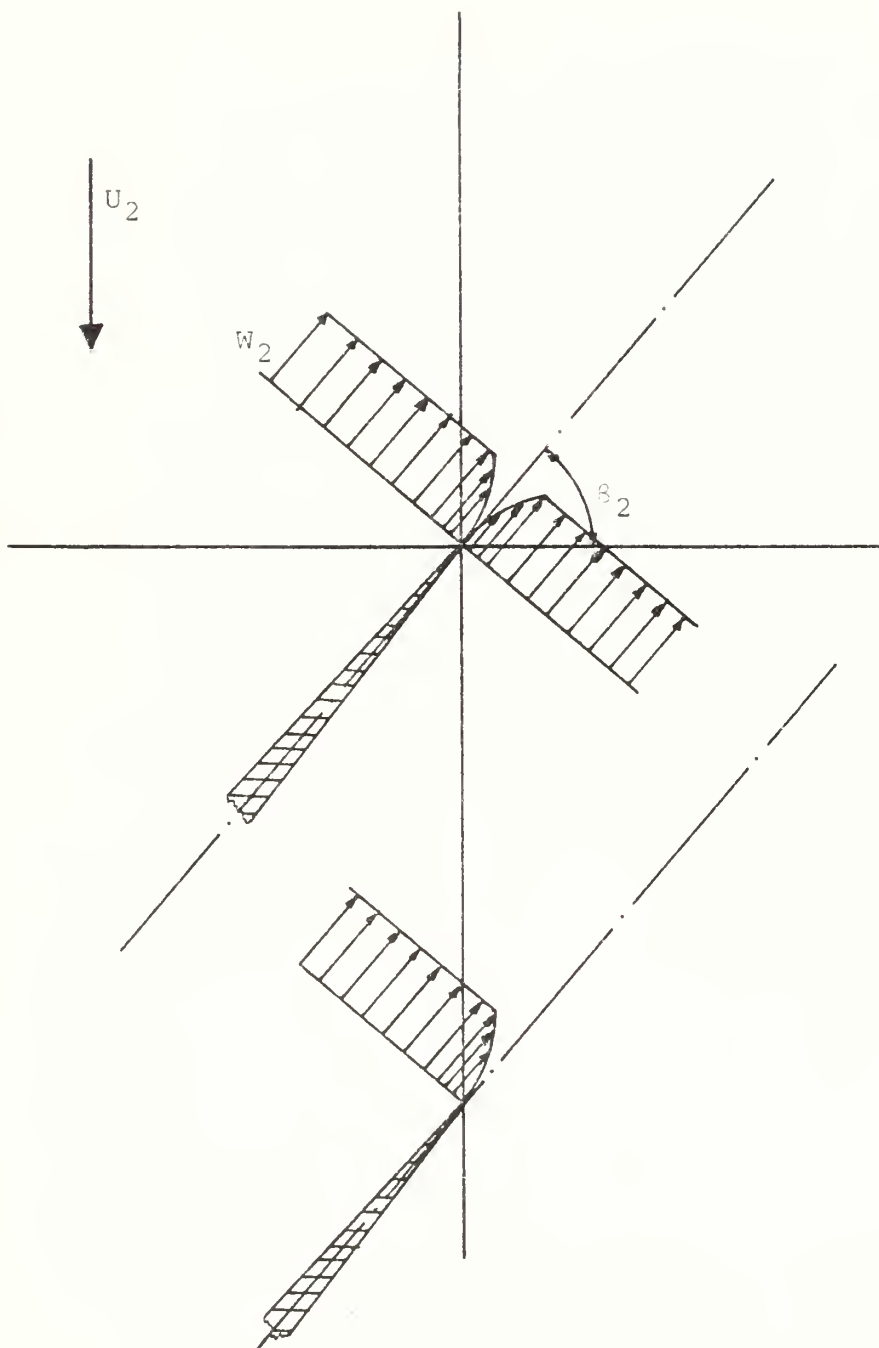
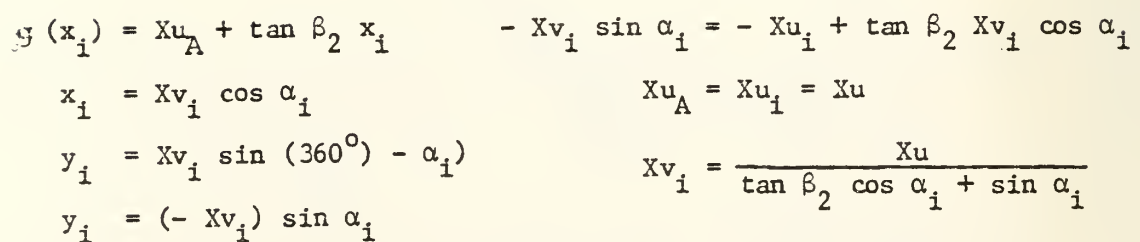


Figure 22. Relative Velocity Distribution W_2 at Rotor Trailing Edge (Schematic)

$$U_2 = \text{const.}$$



94

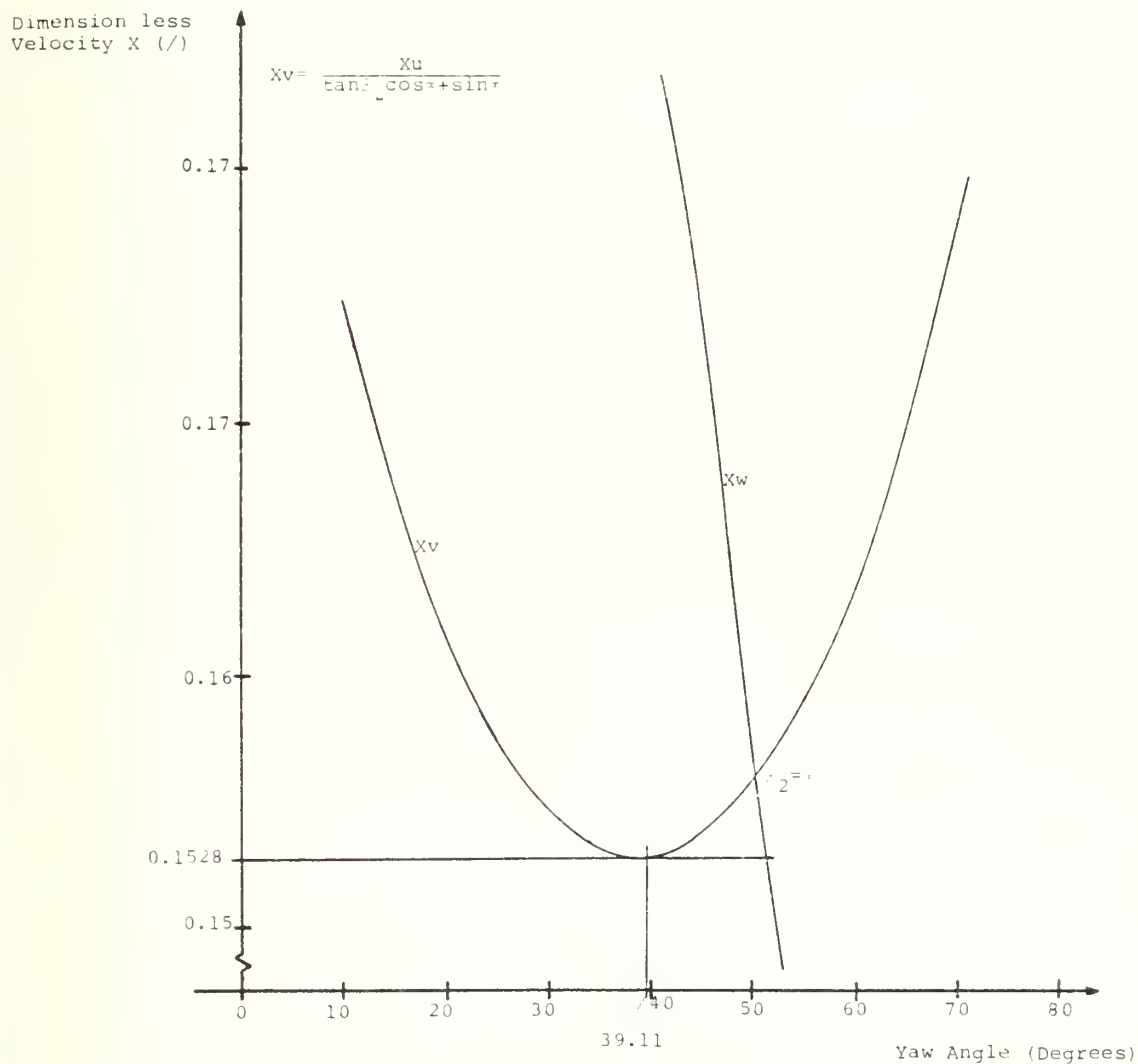


Figure 24. Dependence of Absolute (X_v) and Relative (X_w) Velocities on Yaw Angle (α) Assuming Constant Values of Circumferential Velocity ($X_u=0.24219$) and Relative Flow-Angle ($\beta_2=50.89^\circ$).

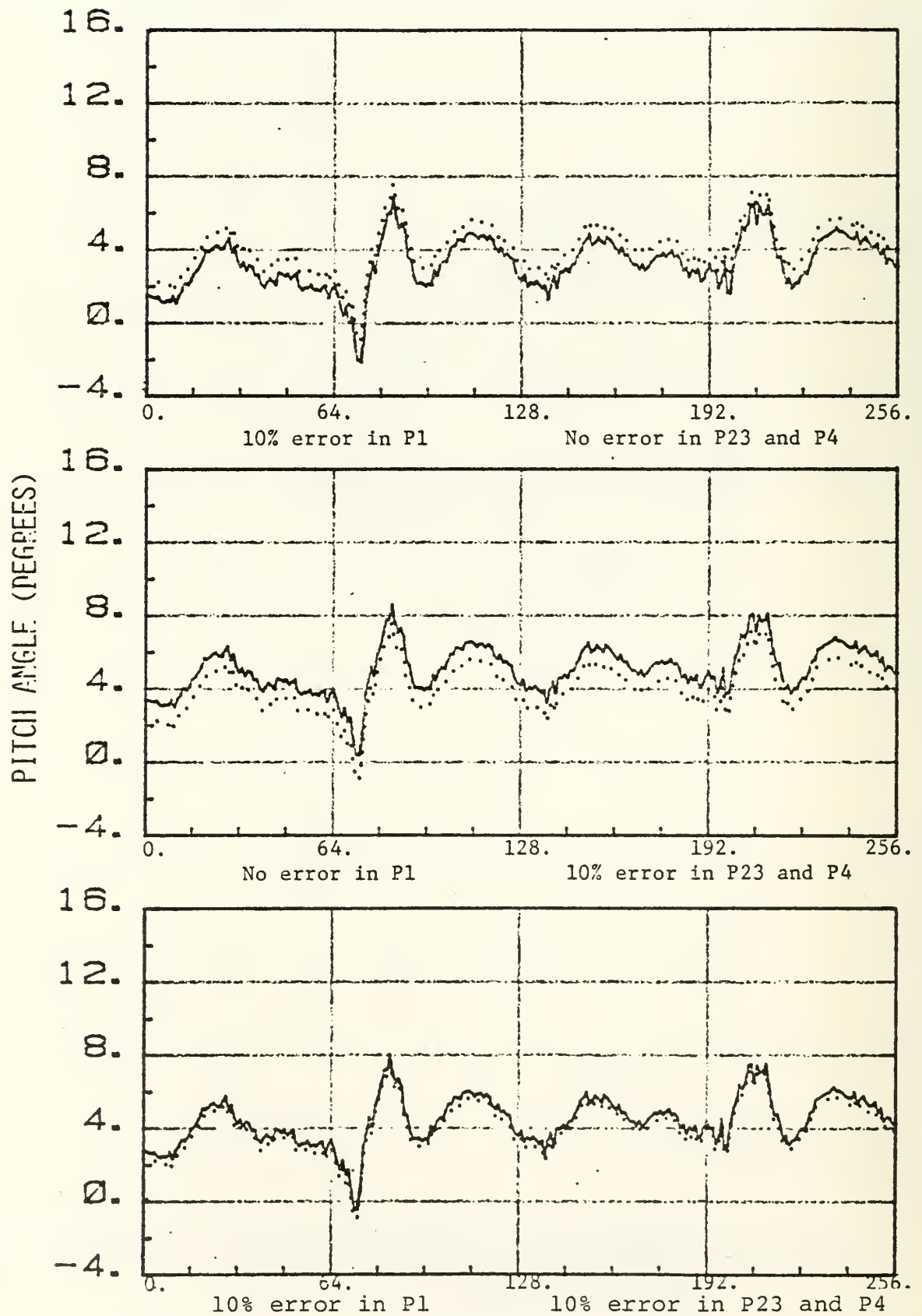


Figure 25. Influence of Incorrect Pneumatic Probe Pressure Readings Run 11
50% Design Speed, Near Peak Efficiency, Dotted Line - No Errors

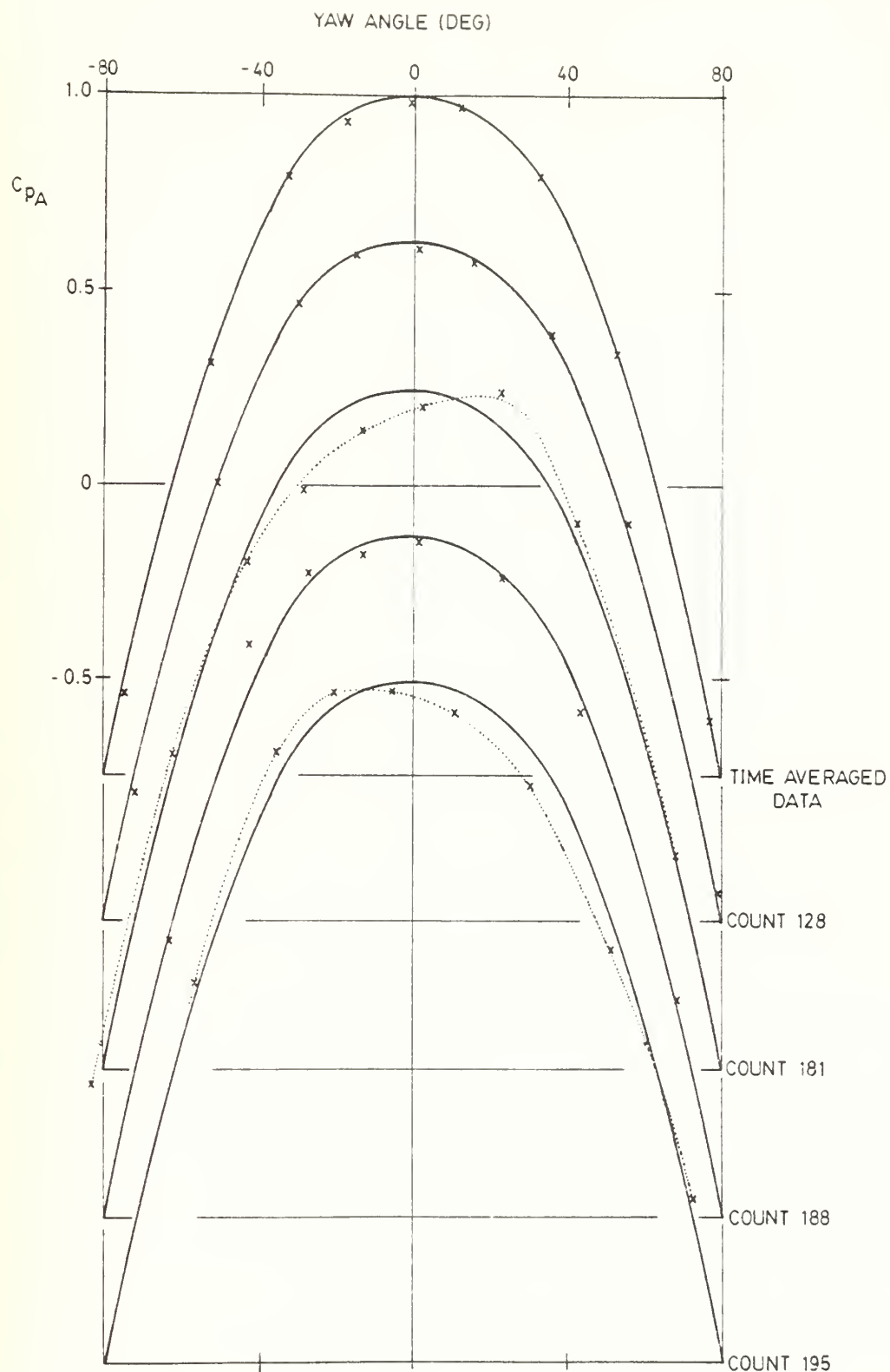


Figure 26. Pressure Coefficient Versus Yaw Angle for Type A Probe at Specific Positions in Rotor Flow Field (Run 123 - solid line is from calibration at $M = 0.4$, $\phi = 0^\circ$).

APPENDIX A

CHANGES MADE TO SOFTWARE FROM (Ref. 4)

The changes made by McCarville and reported in Ref. 4 brought about two general improvements: hardware changes which eliminated the need for an operator-performed lock-on procedure and software changes which allowed the acquisition of one sample for each consecutive revolution instead of every tenth or eleventh as before. In the process of integrating the new software into the data acquisition program, one minor and one significant error was found in the subroutines used for acquiring data through the A/D converter.

The data is transferred from the A/D converter to the 21MX computer in 16-bit words. Only the highest 10 bits contain the digitized voltage while the A/D channel number (0 through 15) is transferred in the lowest 4 bits. Using the highest bit for the sign, the range of numbers which can be transferred is thus $\pm(2^{15}-1)$ or $\pm 32,767$, while the smallest meaningful division is 2^6 or 64. The resolution which can be achieved therefore is $\frac{2^6}{2^{16}}$ or 2^{-10} or 0.000976 of full range. Since the full range of the A/D is -1V to +1V, the instrument resolution is to about 2 mV.

The procedure of masking can be used to derive an exact digital number solely from the highest 10 bits of the transmitted word. If this is not done, the A/D channel number from the low bits is included when converting the data word to a decimal number. The result is to create decimal numbers which appear

to be changing with a resolution of 2° is $\pm 32,767$ or 0.0305 mvs. Since the increase in program running time due to masking was insignificant, this procedure was built into the data acquisition program.

The second error was found while using the data acquisition program. It was noted that a different number of samples acquired from the same machine conditions did not bring any significant change in the smoothness of the output. An examination of the output of 5 individual samples (Table A-I) and the average derived from these samples showed that only the first sample was converted from an integer into a real number and that the same real number resulted for each individual sample no matter what was the value of the integer.

Figure A-1 shows the listing of the original subroutine (RSPACE) from McCarville which acquires raw data. The single samples are read into array IBUFF(99) correctly (lines #90 and #125). The conversion into real numbers is incorrect, in that only the first value of the array IBUFF(99) is converted.

Figure A-2 shows the corrected DO-loop.

Table A-II shows values achieved using the corrected subroutine. It can be seen that changes in the integer numbers are reflected in the calculated real numbers.

In the acquisition program discussed herein a subroutine similar to the one of Fig. A-2 was used.

REP # =	1IBUF =	-115.94	200FF =	-1.3591
REP # =	2IBUF =	-15125	200FF =	-1.3591
REP # =	3IBUF =	-19240	200FF =	-1.3591
REP # =	4IBUF =	-22400	200FF =	-1.3591
REP # =	5IBUF =	-25615	200FF =	-1.3591
POINT # =	XY(I) =	-1.000000		
REP # =	1IBUF =	-15005	200FF =	-1.515525
REP # =	2IBUF =	-20415	200FF =	-1.515525
REP # =	3IBUF =	-22592	200FF =	-1.515525
REP # =	4IBUF =	-25684	200FF =	-1.515525
REP # =	5IBUF =	-25024	200FF =	-1.515525
POINT # =	XY(I) =	-1.125000		
REP # =	1IBUF =	25188	200FF =	1.707115
REP # =	2IBUF =	22344	200FF =	1.707115
REP # =	3IBUF =	21312	200FF =	1.707115
REP # =	4IBUF =	19360	200FF =	1.707115
REP # =	5IBUF =	14400	200FF =	1.707115
POINT # =	XY(I) =	1.125000		
REP # =	1IBUF =	22050	200FF =	1.733250
REP # =	2IBUF =	19500	200FF =	1.733250
REP # =	3IBUF =	16320	200FF =	1.733250
REP # =	4IBUF =	11340	200FF =	1.733250
REP # =	5IBUF =	6720	200FF =	1.733250
POINT # =	XY(I) =	1.125000		
REP # =	1IBUF =	-12132	200FF =	-1.552500
REP # =	2IBUF =	-14529	200FF =	-1.552500
REP # =	3IBUF =	-25550	200FF =	-1.552500
REP # =	4IBUF =	-4095	200FF =	-1.552500
REP # =	5IBUF =	-1372	200FF =	-1.552500
POINT # =	XY(I) =	-1.125000		

Table A-I. Results Using Uncorrected Subroutine
RSPACE (& A2D, McCarville, Ref. 4)

REP # =	1IBUF =	-28736	RBUF =	.976953
REP # =	2IBUF =	-28608	RBUF =	-.973047
REP # =	3IBUF =	-28736	RBUF =	-.976953
REP # =	4IBUF =	-28608	RBUF =	-.973047
REP # =	5IBUF =	-28608	RBUF =	-.973047
POINT # =	1Y(I) =	-.874609		
REP # =	1IBUF =	-28480	RBUF =	-.969141
REP # =	2IBUF =	-28416	RBUF =	-.967188
REP # =	3IBUF =	-28480	RBUF =	-.969141
REP # =	4IBUF =	-28352	RBUF =	-.965234
REP # =	5IBUF =	-28416	RBUF =	-.967188
POINT # =	2Y(I) =	-.867578		
REP # =	1IBUF =	-28160	RBUF =	-.959375
REP # =	2IBUF =	-28096	RBUF =	-.957422
REP # =	3IBUF =	-28160	RBUF =	-.959375
REP # =	4IBUF =	-28096	RBUF =	-.957422
REP # =	5IBUF =	-28224	RBUF =	-.961328
POINT # =	3Y(I) =	-.858984		
REP # =	1IBUF =	-27904	RBUF =	-.951563
REP # =	2IBUF =	-27712	RBUF =	-.945703
REP # =	3IBUF =	-27840	RBUF =	-.949609
REP # =	4IBUF =	-27776	RBUF =	-.947656
REP # =	5IBUF =	-27776	RBUF =	-.947656
POINT # =	4Y(I) =	-.848438		
REP # =	1IBUF =	-27264	RBUF =	-.932031
REP # =	2IBUF =	-27392	RBUF =	-.935938
REP # =	3IBUF =	-27456	RBUF =	-.937891
REP # =	4IBUF =	-27392	RBUF =	-.935938
REP # =	5IBUF =	-27520	RBUF =	-.939844
POINT # =	5Y(I) =	-.836328		

Table A-II. Results Using Corrected Subroutine
RSPACE (&A2D, McCarville, Ref. 4)

```

0082 SUBROUTINE RPACE (ICHA,N,IAVG (SURV (MODE, PAIR
0083 CIPOSIT, IOFFS, N2))
0084 .....
0085 C C
0086 C DATA ACQUISITION SUBROUTINE
0087 C
0088 C
0089 REAL SRUPT(256)
0090 DIMENSION IBUFF(99), ITIME(5)
0091 N=IAVG
0092 CALL EXEC (11, ITIME, IYEAR)
0093 WRITE (6, 20) N2, ITIME(5), IYEAR
0094 20 FORMAT(//, 10X, " THIS IS TEST #", I2, " 2 OF 10"
0095 * " DATE ", I3, 3X, I4, //)
0096 IF (ISURV .EQ. 1) GO TO 120
0097 C .....
0098 C
0099 C SINGLE POINT ACQUISITION
0100 C
0101 C .....
0102 IBLADE=256*(IPAIR-1)+IPOSIT
0103 IF (IMODE .EQ. 0) GO TO 100
0104 IBLADE=IBLADE+1000000
0105 100 CALL EXEC (3, 19)
0106 CALL EXEC (1, 19, IRPM, 1, IBLADE)
0107 CALL EXEC (1, 20, IBUFF, N, ICHAN, 1)
0108 DO 110 I=1, IAVG
0109 110 RBUFF=RBUFF+FLOAT(IBUFF(I))/32768.
0110 PTDATA=RBUFF/IAVG
0111 GO TO 195
0112 C .....
0113 C
0114 C SURVEY ACROSS BLADE PAIR ACQUISITION
0115 C
0116 C .....
0117 120 IF (IOFFS .EQ. 0) GO TO 125
0118 IOFFS=100/IOFFS
0119 GO TO 127
0120 125 IOFFS=1
0121 127 DO 140 J=1, 256
0122 IBLADE=256*(IPAIR-1)+J+256/3*IOFFS+1000000
0123 CALL EXEC (3, 19)
0124 CALL EXEC (1, 19, IRPM, 1, IBLADE)
0125 CALL EXEC (1, 20, IBUFF, N, ICHAN, 1)
0126 RBUFF=0.0
0127 DO 130 K=1, IOFFS
0128 130 RBUFF=RBUFF+FLOAT(IBUFF)/32768.
0129 DATA=RBUFF/IAVG
0130 SRUPT(J)=DATA
0131 C .....
0132 C
0133 C OUTPUT TABLES/PRINT
0134 C
0135 C .....
0136 WRITE (6, 146)
0137 146 FORMAT(//, 13X, "PAGED SURVEY DATA", //)
0138 WRITE (6, 148) SRUPT
0139 148 FORMAT(8(2X, F8.7))
0140 RPM=60/(IRPM*.000001)
0141 WRITE (6, 165) RPM
0142 165 FORMAT(//, 20X, "COMPRESSOR RPM FOR THIS RUN WAS "
0143 *F7.2, //)
0144 GO TO 999
0145 195 WRITE (6, 196) IPOSIT, IPAIR, PTDATA
0146 196 FORMAT(" THE DATA VALUE FOR POSITION ", I3, " OF BLADE PAIR "
0147 *I2, " IS ", F10.7)
0148 GO TO 190
0149 999 RETURN
0150 END

```

Figure A-1. Unchanged Listing of Subroutine RPACE from Program & A2D (P. McCarville, Ref. 4)

```

0121      127 DO 140 J=1,255
0122          IOLADE=255*(IPAIR-1)+1+25+7*(OFFS+1000000)
0123          CALL EXEC (3,19)
0124          CALL EXEC (1,19,IRPM,1,IOLADE)
0125          CALL EXEC (1,20,IBUFF,N,ICHAN,0)
0126          RBUFF=0.0
0127          DO 130 K=1,N
0128      130 RBUFF=RBUFF+FLOAT(IBUFF(K))/32768.
0129          DATA=RBUFF/IAVG
0130      140 SRVPT(J)=DATA

```

Figure A-2. Corrected Statement of Subroutine
RSPACE from Program &A2D (P. McCarville, Ref. 4)

APPENDIX B

OUTPUT CHARACTERISTICS OF TYPE "A" AND TYPE "B" PROBES

The DPDS, measurements are carried out using two different kinds of pressure probes. The type "A" probe is essentially a total pressure probe (see Fig. 4). The general behavior of such a probe with respect to angle changes has been established for quite some time (Ref. 10). However, using a pneumatic equivalent probe to the "A" probe the output of the probe as a function of yaw angle was established with the probe mounted in the steady flow of a freejet.

Figure B-1 shows this dependence. The characteristics of this curve are a flat top, indicating an insensitivity of the probe to yaw angle changes of up to $\pm 20^\circ$ from the zero yaw angle position, and the steep but almost linear parts from -70° to -40° and $+40^\circ$ to $+70^\circ$. At yaw angles of -63° and $+63^\circ$ the probe reads static pressure and that happens independent of Mach number and pitch angle as long as the pitch angle does not exceed a range of -5° to about $+15^\circ$.

Figure 9 shows the output of the type "A" probe for different pitch angle settings but one Mach number only. It can be seen that pitch angles ranging from -15° to $+25^\circ$ at a 5° increment produce almost identical curves.

Figure 12 shows the output of the type "B" probe for the same Mach number and the same range of pitch angle. It can be seen that, compared to the "A" probe

probe does not have a flat top for a range of measurement close to the zero yaw angle (zero being the yaw angle where the probe is aligned with the flow). Instead it shows a clear and well-defined maximum in output for the zero yaw angle. It is also evident that the output depends very clearly on the pitch angle. The yaw angle where the probe reads static pressure is different for different pitch angles and Mach numbers. Different Mach numbers always show only one curve for the "A" probe (independent of pitch angle) while the "B" probe depends on changes of both Mach number and pitch angle .

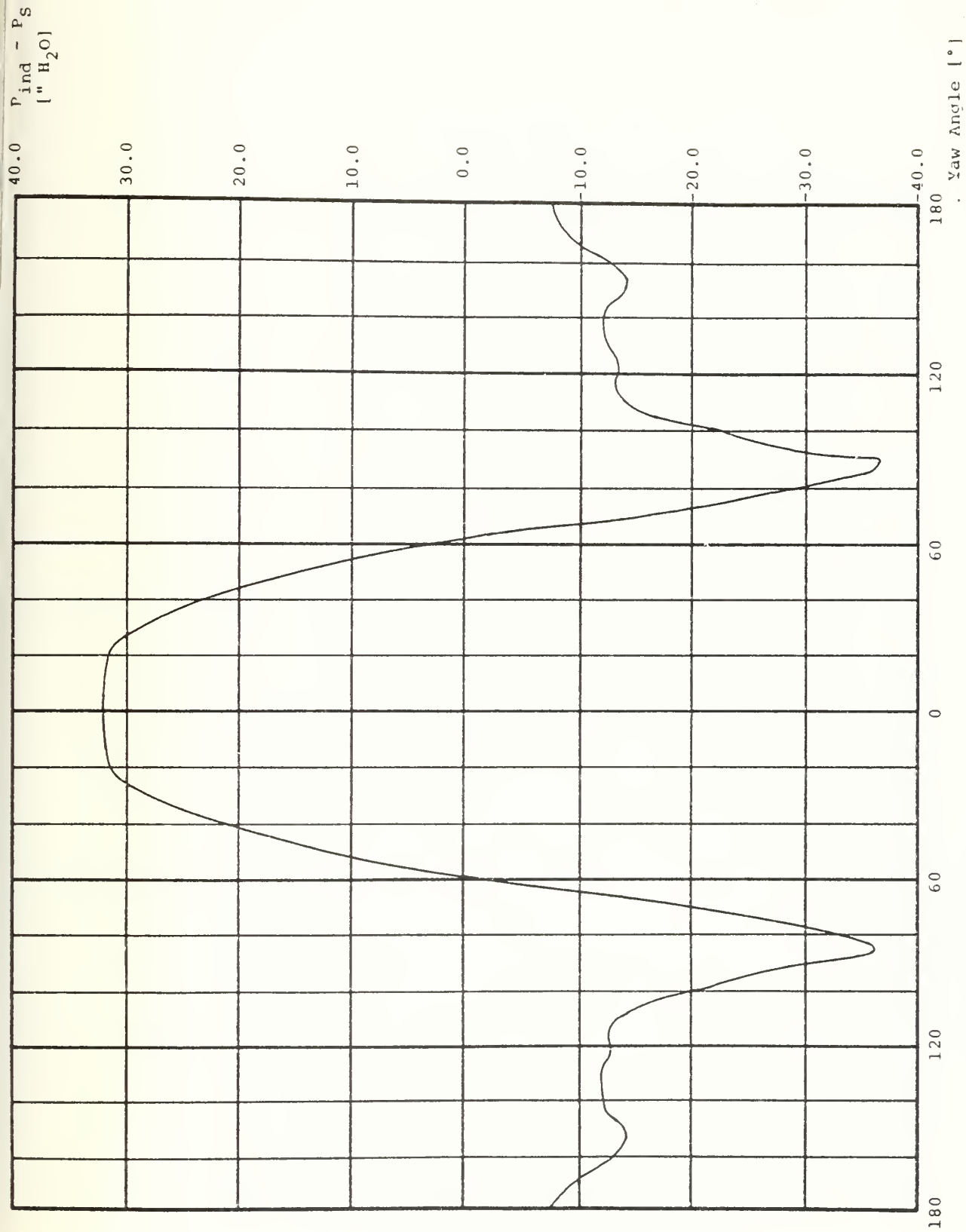


Figure B-1. Indicated Pressure Versus Yaw Angle for a Pneumatic Probe Equivalent to a Type A probe. Dynamic Head = 32 " H₂O. Free Jet Flow, Zero Degrees Pitch Angle.

APPENDIX C

DATA ACQUISITION PROGRAMS &KALIB AND &YAW

The purpose of both programs--&YAW and &KALIB--is to acquire sufficient data for the calibration of either the type "A" or "B" probe. It has to be mentioned here that only one probe can be mounted in the center of the freejet at a time. It is therefore essential to establish identical conditions for the calibration of both probes.

Since the data reduction as outlined in 4.1 requires not only the knowledge of Mach number and pitch angle, but also the probe output characteristic as a function of yaw angle, data is acquired for different yaw angle settings. Here is the major difference between programs &YAW and &KALIB. While program &YAW requires the data acquisition at one specific yaw angle setting, &KALIB acquires data in a continuous mode for a range of 160° (-80° to $+80^{\circ}$) in yaw angle.

However, program &YAW will be described first, since it is the more conventional one.

C-1. PROGRAM &YAW

Since parameters have to be changed during a calibration, the program has to work interactively with operator input. For each selected combination of Mach number and pitch angle data can be recorded for up to 31 probe yaw angle settings. For any of these settings the values of total pressure, Kulite reference pressure, probe yaw angle and Kulite

pressure reading are acquired as the average of 10 data samples each. The pitch angle is keyed in by the operator prior to the measurement and the total temperature and the barometric pressure (static pressure since it is a freejet) are measured also. When the data for one yaw angle position is taken the operator is asked to have the probe moved to another yaw angle and initialize the data acquisition process again.

Once the data for all 31 yaw positions are taken, the operator is asked to key in a file name. The raw data from this calibration is then stored in a file with the name previously assigned.

In the next step absolute values for the total temperature (degrees Fahrenheit) and the static pressure (inches Hg) are calculated. File name, pitch angle, total temperature and static pressure are written on the line printer. The following DO-loop derives absolute values of the impact pressure (inches of water), the Kulite reference pressure (inches of water), the probe yaw angle (degrees), and the Kulite pressure output (inches of water) as a gage pressure. From these values a pressure coefficient c_p defined as

$$c_p = \frac{p_K + p_{\text{ref}} - p_s}{p_t - p_s}$$

where p_K = Kulite pressure

p_{ref} = Kulite reference pressure

p_t = total pressure

p_s = static pressure

is derived. All of these values are tabulated.

A plot of c_p vs yaw angle is produced automatically with the operator's choice of drawing a full grid or just the calibration result.

After this the program can either be stopped or started again for a different flow condition.

C-1 gives a flow chart, while C-2 is a program listing.

Externals: ABRT, CLEAR, CLOSE, CPLOT, CREAT, DRAW, FXD, LABEL, LDIR, LOCL, MOVE, OPEN, PLOTR, RMOTE, SCANR, SETAR, VIEWP, WINDOW, WRITF

<u>Variables</u>	<u>Type</u>	<u>Description</u>
CDATA(32)	Real	Array containing pressure coefficients c_p
DATA(32,4)	Real	Array containing complete raw calibration data
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphic data control block
IL	Integer	Total number of words to be stored in raw data file (two words for one data value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file
S T U V	Real	total pressure Kulite ref. pressure probe yaw angle Kulite output
W X Y Z	Real	total pressure Kulite ref. pressure Average values of probe yaw angle Kulite output

C-2. PROGRAM &KALIB

As stated earlier this program records probe data for more yaw positions than program &YAW. Once either the "A" or the "B" probe is mounted on the freejet and the desired flow condition (Mach number and pitch angle) is established, the actual pitch angle is keyed in, and single measurements of total temperature and pressure as well as Kulite reference pressure and barometric pressure are taken. The operator is then asked to start the data acquisition process for the Kulite pressure/yaw angle measurement. Simultaneously the operator has to signal that the probe shall be rotated in the freejet. While the probe is rotated from -80° to $+80^{\circ}$ in yaw at a constant rate of $\sim 3^{\circ}/\text{sec}$, the yaw position and the corresponding Kulite pressure reading is recorded alternately. When the whole range of yaw angle is finished, the flow conditions are recorded again and the probe is rotated backwards 160° with the same data acquisition process as before. Then the jet conditions are recorded a third time. All raw data is multiplied by its corresponding scaling factor. The total temperature is calculated in degrees Fahrenheit. A pressure coefficient as defined in C-1 is derived for all 300 points of measurement. The whole data array (contents are defined in the listing) is stored in one file with its name as operator input. A complete output of the file contents is printed. (Note: line printer must be set to "comp".)

The operator is then asked to specify the form of a plot of the just-acquired data. When the plot is completed the operator has the choice of stopping the program or performing another data acquisition for a different flow condition.

C-3 gives a flow chart of &KALIB while C-4 is a program listing.

Externals: ABRT, CLEAR, CLOSE, CPLOT, CREAT, DRAW, FXD, LABEL, LDIR, LOCL, MOVE, OPEN, PLOTR, RMOTE, SCANR, SETAR, VIEWP, WINDOW, WRITE

<u>Variables</u>	<u>Type</u>	<u>Description</u>
CDATA(300)	Real	Array containing pressure coefficients C_p
DATA(2,320)	Real	Array containing complete raw calibration data
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphic data control block
IL	Integer	Total number of words to be stored in raw data file (two words for one data value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file

By comparison of sets of data acquired with both programs for the same flow conditions, no difference was found between the results of the two programs.

Since program &KALIB offers much more overall information in even shorter time, it was used for the whole calibration of both probes with occasional comparisons between the two program results. Plots of the probe outputs vs yaw angle were produced and stored for each of the conditions to have an easy and clear idea of the probe's general behavior.

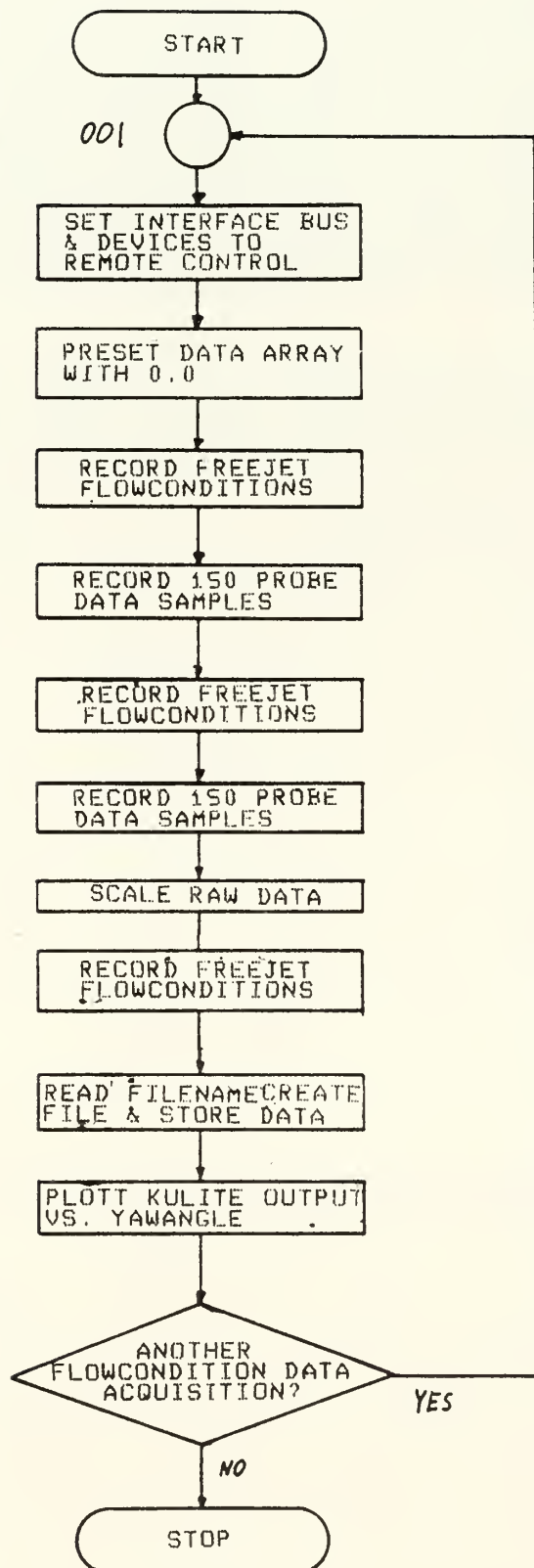


Figure C-1. Flow Chart of Data Acquisition Program & Yaw

```

&YAW T=00004 IS ON CR00026 USING 00025 BLKS R=0000
FTN4,L
0001 PROGRAM YAW
0002 REAL DATA(32,4),CDATA(32)
0003 DIMENSION IGCR(192),IDCR(144),IFILE(3),ISIZE(2)
0004 DATA IGCR/144/
0005 DATA IDCR/0/
0006 DATA ICR/29/
0007 DATA ITYPE/1/
0008 DATA ISIZE/2,128/
0009 DATA IL/256/
0010
0011 .....
0012
0013
0014
0015
0016
0017
0018
0019
0020
0021
0022
0023
0024
0025
0026
0027
0028
0029
0030
0031
0032
0033
0034
0035
0036
0037
0038
0039
0040
0041
0042
0043
0044
0045
0046
0047
0048
0049
0050
0051
0052
0053
0054
0055
0056
0057
0058
0059
0060
0061
0062
0063
0064
0065
0066
0067
0068
0069
0070
0071
0072
0073
0074
0075
0076
0077
0078

PROGRAM YAW
REAL DATA(32,4),CDATA(32)
DIMENSION IGCR(192),IDCR(144),IFILE(3),ISIZE(2)
DATA IGCR/144/
DATA IDCR/0/
DATA ICR/29/
DATA ITYPE/1/
DATA ISIZE/2,128/
DATA IL/256/

.....

PROGRAM TO ACQUIRE DATA FOR THE CALIBRATION OF A KULITE PROBE
THIS PROGRAM TAKES DATA AT DEFINED YAW POSITIONS.
ONLY THE RAW DATA IS STORED.

.....

101 FORMAT (" READ PITCHANGLE FROM TERMINAL!")
102 FORMAT ("I4")
103 FORMAT (" WHEN YOU ARE READY FOR THE "I4". MEASUREMENT, HIT CR !")
104 FORMAT (" Pt tunnel="F8.6" P ref.="F8.6" Probe pos.="F8.6" Kulite
105 FORMAT (" Pt tunnel="F8.6")
106 FORMAT (" ENTER THE FILE NAME YOU WANT THE RAW DATA TO BE STORED IN
107 FORMAT (" IF YOU NEED A COMPLETE NEW FRAME, KEY YE !"/" ANY OTHER Y
108 FORMAT (" KEY IF NOT!")
109 FORMAT (" IF YOU WANT ANOTHER SET OF DATA FOR A DIFFERENT PITCH AND
110 FORMAT (" KEY YES"/" ANYTHING ELSE, IF NOT!")
111 FORMAT ("(3A2)")
112 FORMAT (" RAW DATA ARE STORED IN FILE : "I4,3A2/)
113 FORMAT (" Pitch ="I4" Tunnel Temp.="F8.2"P baro="F8.5//)
114 FORMAT (" YAW Kulite out P ref. Pt tunnel"16X"C
115 FORMAT ("P"/)
116 FORMAT ("I4,I4,F7.3,3(I4,F12.6),6X,F12.6)
117 FORMAT ("CA")
118 FORMAT ("F1R7H3A1H0T3")
119 FORMAT ("F1R7H3A0H0T3")
120 FORMAT (" I="I5,IERR="I5,F12.4)
121 FORMAT ("R-PROBE PITCH="I4,10X"P BARO="F7.3)
122 FORMAT ("TUNNEL TEMPERATURE="F7.3,2X"FILE : "3A2)
123 FORMAT (" CP")
124 FORMAT ("CA")

.....

DATA LOCATION IN THE DATA FILE :
FOR I = 1 TO 31, I IS THE NUMBER OF THE YAW ANGLE.
FOR EACH OF THESE YAW ANGLES THE ARRAY CONTAINS THE FOLLOWING
VALUES IN THE GIVEN ORDER:

# 1 Pt tunnel 1 P ref. Kulite 2 Probe position 3 Kulite press. 4
# 2 " " " " " "
# 31 " " " " " "

DATA(32,1) contains pitchangle input from terminal
DATA(32,2) contains Pt tunnel read from scanr #2 ch 6
DATA(32,3) contains P baro read from scanr #1 ch 25

.....

001 CALL ABRT(7,2)
CALL RMOTE(8)
CALL RMOTE(10)
CALL RMOTE(15)
WRITE (8,801)
WRITE (10,1001)
WRITE (15,1501)

.....

PRESET DATA ARRAY WITH 0.0 !

.....

DO 002 I = 1,32,1

```

Figure C-2. Listing of Calibration Data Acquisition Program &YAW.
(Continued on next page.)

```

0079      DATA(I,1) = 0.0
0080      DATA(I,2) = 0.0
0081      DATA(I,3) = 0.0
0082      DATA(I,4) = 0.0
0083      DATA(32,2) = SCANR(15,06,01)
0084      DATA(32,3) = SCANR(08,25,01)
0085      WRITE(1,101)
0086      READ(1,102) DATA(32,1)
0087      WRITE(10,1002)
0088      DO 010 I = 1,31,1
0089      003  WRITE(1,103) I
0090      READ(1,149) IDUM
0091      IF (IDUM .NE. 2H ) GOTO 003
0092      W = 0
0093      X = 0
0094      Y = 0
0095      Z = 0
0096
0097      DO 008 J = 1,10,1
0098      S = SCANR(15,20,01)
0099      W = W + S
0100      T = SCANR(15,21,01)
0101      X = X + T
0102      U = SCANR(15,22,01)
0103      Y = Y + U
0104      V = SCANR(15,23,01)
0105      Z = Z + V
0106      DATA(I,1) = W/10
0107      DATA(I,2) = X/10
0108      DATA(I,3) = Y/10
0109      DATA(I,4) = Z/10
0110      010  WRITE(1,104) (DATA(I,J),J= 1,4,1)
0111      WRITE(1,105)
0112      READ(1,149) IFILE
0113      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
0114      JJ = 1
0115      IF (IERR .LT. 0 ) WRITE(1,111) JJ,IERR
0116      CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
0117      JJ = 2
0118      IF (IERR .LT. 0 ) WRITE(1,111) JJ,IERR
0119      CALL WRITF (IDCB,IERR,DATA,IL)
0120      JJ = 3
0121      IF (IERR .LT. 0 ) WRITE(1,111) JJ,IERR
0122      CALL CLOSE (IDCB,IERR,0)
0123      JJ = 4
0124      IF (IERR .LT. 0 ) WRITE(1,111) JJ,IERR
0125      DATA(32,2) = 32.6149 + 34727.9 * DATA(32,2)
0126      DATA(32,3) = DATA(32,3) * 10000
0127      WRITE(6,601) IFILE
0128      WRITE(6,602) DATA(32,1),DATA(32,2),DATA(32,3)
0129      WRITE(6,603)
0130      DO 020 I = 1,31,1
0131      DATA(I,1) = DATA(I,1) * 10000
0132      DATA(I,1) = DATA(I,1) * 10
0133      DATA(I,2) = DATA(I,2) * 10000
0134      DATA(I,3) = DATA(I,3) * 10000
0135      DATA(I,4) = DATA(I,4) * 10000
0136      CDATA(I) = (DATA(I,4) + DATA(I,2)) / DATA(I,1)
0137      020  WRITE(6,604) I,DATA(I,3),DATA(I,4),DATA(I,2),DATA(I,1),CDATA(I)
0138
0139      CALL CLEAR (7,1)
0140      CALL LOCL (7)
0141      CALL PLOTR (IGCB,2,1,13)
0142      CALL SETAR (IGCB,1.5)
0143      CALL VIEWP (IGCB,30.,110.,20.,70.0)
0144      CALL WINDOW (IGCB,-80.,80.,-1.0,1.0)
0145      CALL FXD (IGCB,1)
0146      WRITE(1,106)
0147      READ(1,149) IDUM
0148      IF (IDUM.EQ.2H)E) CALL LGRID (IGCB,-5.,0.5,0.0,0.0,4.0,1.0,1.0)
0149      CALL MOVE (IGCB,DATA(1,3),CDATA(1))
0150      DO 040 I=1,31,1
0151      040  CALL DRAW (IGCB,DATA(I,3),CDATA(I))
0152      CALL VIEWP (IGCB,0.,150.,0.,100.)
0153      CALL WINDOW (IGCB,0.,150.,0.,100.)
0154      CALL MOVE (IGCB,22.,15.)
0155      CALL CPLOT(IGCB,-8.,0.,0)
0156      CALL LABEL (IGCB)
0157      WRITE(13,1301)DATA(32,1),DATA(32,3)
0158      CALL MOVE (IGCB,22.,10.)

```

Figure C-2. Listing of Calibration Data Acquisition Program &YAW.
(Continued on next page.)


```

0159 CALL CPLOT (IGCB,-8.,0.,0.)
0160 CALL LABEL (IGCB)
0161 WRITE (13,1302) DATA(32,2),IFILE
0162 CALL MOVE (IGCB,18.0,20.)
0163 CALL CPLOT (IGCB,-8.,0.,0.0)
0164 CALL LDIR (IGCB,+1.57)
0165 CALL LABEL (IGCB)
0166 WRITE (13,1303)
0167 WRITE(1,107)
0168 READ(1,149) IDUM
0169 IF (IDUM.EQ. 2HYE) GOTO 1
0170 STOP 7777
0171 END
0172 REAL FUNCTION SCANR (LU,ICHAN,K)
0173 .....
0174 .
0175 . Close relay ICHAN on scanner LU and read the instrument
0176 . indicated by K.
0177 . Author: Robert N. Geopfarth
0178 . Date: February 31, 1979
0179 . Detailed program description is available in TXCO log; the
0180 . variables are:
0181 . LU ... LU# of desired scanner (8 or 15).
0182 . ICHAN ... Scanner channel (integer).
0183 . IC ... Scanner channel (ASCII).
0184 . K ... Instrument code ( DVM = 1 / Counter = 2 ).
0185 .
0186 .....
0187 * Closes scanner and reads DVM, counter. *
0188 101 FORMAT (A2)
0189 801 FORMAT ("C")
0190 1001 FORMAT ("T3T3")
0191 1201 FORMAT ("I")
0192 1501 FORMAT ("C")
0193
0194 WRITE ( 8, 801)
0195 WRITE (15,1501)
0196 IC = ICON(ICHAN,0)
0197 WRITE (LU, 101) IC
0198 GO TO (01,02) K
0199
0200 01 CALL TRIGR (10)
0201 READ (10, *) DUM
0202 CALL TRIGR (10)
0203 READ (10, *) SCANR
0204 GO TO 03
0205
0206 02 WRITE (12,1201)
0207 READ (12, *) SCANR
0208
0209 03 WRITE (LU, 801)
0210 RETURN
0211 END
0212 INTEGER FUNCTION ICON(I,N)
0213 IC=I+N
0214 IF(IC.LT.10) GO TO 100
0215 CALL CODE
0216 WRITE(ICON,60)IC
0217 60 FORMAT(I2)
0218 RETURN
0219 100 ICON=IC+30060B
0220 RETURN
0221 END

```

Figure C-2. Listing of Calibration Data Acquisition Program &YAW.

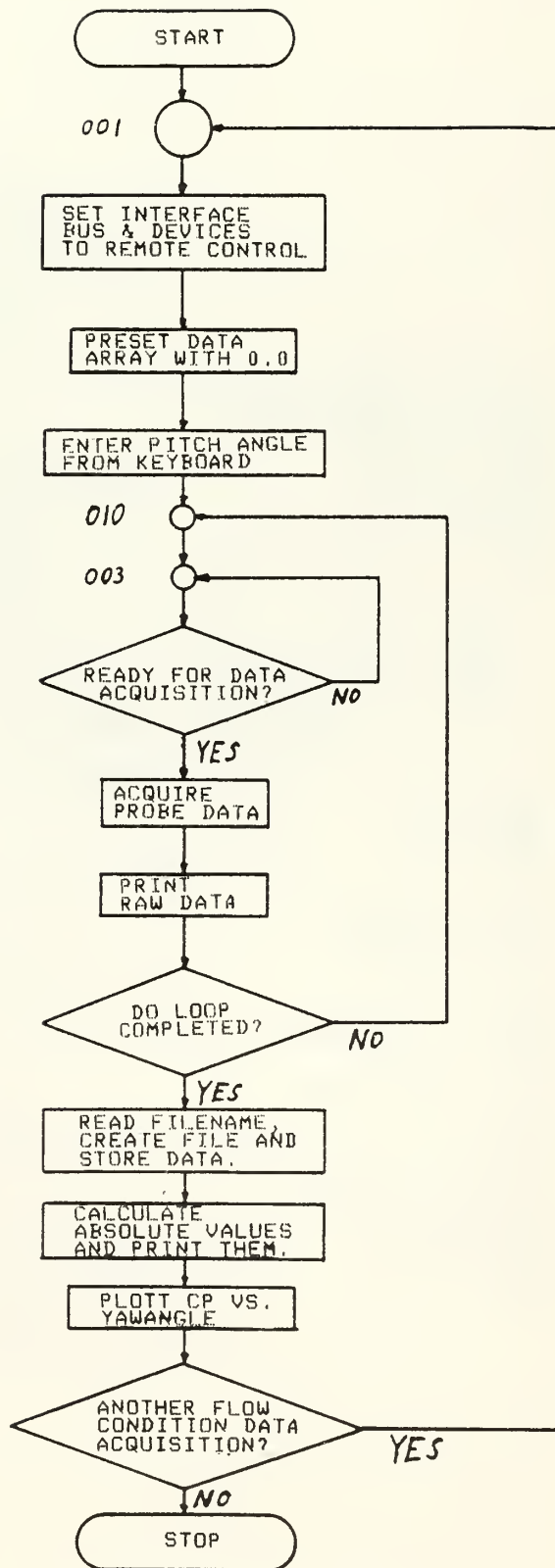


Figure C-3. Flow Chart of Data Acquisition Program & KALIB

KALIB T=00004 IS ON CR00026 USING 00042 BLKS R=0000

```

001 FTN4,L
002 PROGRAM KALIB
003 REAL DATA(2,320),CDATA(300)
004 DIMENSION IDCB(192),IDCB(144),IFILE(3),ISIZE(2)
005 DATA IDCRS /144/
006 DATA ISFCU /0/
007 DATA ICR /27/
008 DATA ITYPE /1/
009 DATA ISIZE /10,128/
010 DATA IL /1280/
011
012 C
013 C
014 C
015 C
016 C
017 101 FORMAT(" READ PITCHANGLE FROM TERMINAL:")
018 102 FORMAT(" WHEN YOU ARE READY FOR THE MEASUREMENT, HIT CR ")
019 103 FORMAT(" FIRST RANGE COMPLETED")
020 104 FORMAT(" WHEN YOU ARE READY TO MOVE THE PROBE BACKWARDS,KEY CR")
021 105 FORMAT(" ENTER THE FILE NAME YOU WANT THE RAW DATA TO BE STORED IN
022 * :")
023 106 FORMAT(" IF YOU NEED A COMPLETE NEW FRAME, KEY YE !"/" ANY OTHER K
024 *EY IF NOT")
025 107 FORMAT(" IF YOU WANT ANOTHER SET OF DATA FOR A DIFFERENT PITCH ANGL
026 *E KEY YES"/" ANYTHING ELSE,IF NOT")
027 149 FORMAT((3A2))
028 601 FORMAT(" RAW DATA ARE STORED IN FILE : "1X,3A2,15X"PITCH = "I4/)
029 602 FORMAT(" TUNNEL TEMP. DEG. F TUNNEL PRESS. INCHES H2O "K R
030 *EF PRESS. INCHES H2O P BARO INCHES HG")
031 603 FORMAT(4(7X,F19.7),5X"BEFORE READINGS"/)
032 604 FORMAT(4(7X,F19.7),5X"BETWEEN READINGS"/)
033 605 FORMAT(4(7X,F19.7),5X"AFTER READINGS"/)
034 606 FORMAT(4(7X,F19.7),5X"AVERAGE VALUES"/)
035 607 FORMAT(" *YAWANG KULITEOUT CP *YAWANG KULITEOUT CP *YAWANG KULITEOUT CP
036 *YAWANG KULITEOUT CP *YAWANG KULITEOUT CP *YAWANG KULITEOUT CP
037 *EOUT CP")
038 608 FORMAT(I3,1X,F6.3,2X,F8.5,1X,F5.3,4(I4,1X,F6.3,2X,F8.5,1X,F5.3))
039 609 FORMAT(1H1)
040 801 FORMAT("CA")
041 1001 FORMAT("F1R7M3A1H0T3")
042 1002 FORMAT("F1R7M3A0H0T3")
043 1111 FORMAT(" *="IS"IEPR = "IS,F12.4)
044 1301 FORMAT("B--PROBE PITCH = "I4,1X"P BARO = "F7.3,1X"FILE = "3A2)
045 1302 FORMAT("TUNNEL TEMPERATURE = "F7.3" TUNNEL PRESS. = "F7.3)
046 1303 FORMAT("KULITE OUTPUT (INCHES H2O)")
047 1501 FORMAT("CA")
048 C
049 C
050 C
051 C
052 C
053 C
054 C
055 C
056 C
057 C
058 C
059 C
060 C
061 C
062 C
063 C
064 C
065 C
066 C
067 C
068 C
069 C
070 C
071 C
072 C
073 C
074 C
075 C
076 C
077 C
078 C

```

DATA LOCATION IN THE DATA FILE :

LOCATION IN FILE :	CONTAINS :
FOR I = 1 TO 300 DATA(1,I)	YAW POSITION
FOR J = 1 TO 300 DATA(2,I)	KULITE PRESS. OUTPUT

LOCATION IN FILE: CONTAINS: READ FROM:

DATA(1,301)	I total tunnel	Ch# 6 Scannr.# 2	
DATA(2,301)	P total tunnel	Ch#20 Scannr.# 3	b e f o r e
DATA(1,302)	K ref. press.	Ch#21 Scannr.# 3	r e a d i n g
DATA(2,302)	Barom. press.	Ch#25 Scannr.# 1	
DATA(1,303)	I total tunnel	Ch# 6 Scannr.# 2	
DATA(2,303)	P total tunnel	Ch#20 Scannr.# 3	b e t w e e n
DATA(1,304)	K ref. press.	Ch#21 Scannr.# 3	r e a d i n g s
DATA(2,304)	Barom. press.	Ch#25 Scannr.# 1	
DATA(1,305)	I total tunnel	Ch# 6 Scannr.# 2	
DATA(2,305)	P total tunnel	Ch#20 Scannr.# 3	a f t e r
DATA(1,306)	K ref. press.	Ch#21 Scannr.# 3	r e a d i n g
DATA(2,306)	Barom. press.	Ch#25 Scannr.# 1	
DATA(1,319)	I total tunnel		a v e r a g e
DATA(2,319)	P total tunnel		o u t p u t
DATA(1,319)	K ref. press.		f r o m t h r e e
DATA(2,319)	Barom. press.		r e a d i n g s a b o v e
DATA(1,329)	Pitch angle		T e r m i n a l

Figure C-4. Listing of Calibration Data Acquisition Program &KALB.
(Continued on next page.)

```

079 C .....
080
081
082 001 CALL ABRT(7,2)
083 CALL RMOTE(8)
084 CALL RMOTE(10)
085 CALL RMOTE(15)
086
087 WRITE (9,801)
088 WRITE (10,1001)
089 WRITE (15,1501)
090
091
092
093 : PRESET NEW DATA ARRAY WITH 0.0
094 :
095 .....
096
097 DO 002 I = 1,320,1
098 DATA(1,I) = 0.0
099 002 DATA(2,I) = 0.0
100 WRITE(1,101)
101 READ (1,*) DATA(1,320)
102 DATA(1,301) = SCANR(15,06,01)
103 DATA(2,301) = SCANR(15,20,01)
104 DATA(1,302) = SCANR(15,21,01)
105 DATA(2,302) = SCANR(08,25,01)
106 WRITE(10,1002)
107 005 WRITE(1,102)
108 READ (1,149) IDUM
109 IF ( IDUM .NE. 2H ) GOTO 005
110 DO 010 I = 1,150,1
111 DATA(1,I) = SCANR(15,22,01)
112 DATA(2,I) = SCANR(15,23,01)
113 DATA(1,303) = SCANR(15,06,01)
114 DATA(2,303) = SCANR(15,20,01)
115 DATA(1,304) = SCANR(15,21,01)
116 DATA(2,304) = SCANR(08,25,01)
117 WRITE(1,103)
118 015 WRITE(1,104)
119 READ(1,149) IDUM
120 IF ( IDUM .NE. 2H ) GOTO 015
121 DO 018 I = 1,151,300,1
122 DATA(1,I) = SCANR(15,22,01)
123 DATA(2,I) = SCANR(15,23,01)
124 DATA(1,305) = SCANR(15,06,01)
125 DATA(2,305) = SCANR(15,20,01)
126 DATA(1,306) = SCANR(15,21,01)
127 DATA(2,306) = SCANR(08,25,01)
128 CALL CLEAR(7,1)
129 CALL LOCL(7)
130 DO 019 I = 1,319,1
131 DATA(1,I) = DATA(1,I) * 10000
132 019 DATA(2,I) = DATA(2,I) * 10000
133 DO 020 I = 301,305,2
134 DATA(1,I) = 32.6149 + 3.47279 * DATA(1,I)
135 DATA(2,I) = DATA(2,I) * 10
136 DATA(1,318) = (DATA(1,301)+DATA(1,303)+DATA(1,305))/3
137 DATA(2,318) = (DATA(2,301)+DATA(2,303)+DATA(2,305))/3
138 DATA(1,319) = (DATA(1,302)+DATA(1,304)+DATA(1,306))/3
139 DATA(2,319) = (DATA(2,302)+DATA(2,304)+DATA(2,306))/3
140 021 DO 021 I = 1,300,1
141 CDATA(I) = (DATA(2,I)+DATA(1,319)) / DATA(2,318)
142 WRITE(1,105)
143 READ (1,149) IFILE
144 CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
145 JJ = 1
146 IF (IERR .LT. 0) WRITE(1,111) JJ,IERR
147 CALL OPEN (IDCB,IERR,IFILE,IOPTR,ISECU,ICR,IDCBS)
148 JJ = 2
149 IF (IERR .LT. 0) WRITE(1,111) JJ,IERR
150 CALL WRITE (IDCB,IERR,DATA,1L)
151 JJ = 3
152 IF (IERR .LT. 0) WRITE(1,111) JJ,IERR
153 CALL CLOSE (IDCB,IERR,0)
154 JJ = 4
155 IF (IERR .LT. 0) WRITE (1,111) JJ,IERR
156 WRITE(6,601) IFILE,DATA(1,320)
157 WRITE(6,602)
158 WRITE (6,603) DATA(1,301),DATA(2,301),DATA(1,302),DATA(2,302)
159 WRITE (6,604) DATA(1,303),DATA(2,303),DATA(1,304),DATA(2,304)

```

Figure C-4. Listing of Calibration Data Acquisition Program &KALIB.
(Continued on next page.)

```

157 WRITE (6,605) DATA(1,305),DATA(2,305),DATA(1,306),DATA(2,306)
160 WRITE (6,606) DATA(1,318),DATA(2,318),DATA(1,319),DATA(2,319)
161 WRITE(6,607)
162 DO 030 I = 1,60,1
163 J = I + 60
164 JJ = J + 60
165 IJ = IJ + 60
166 IJJ = IJJ + 60
167 030 WRITE(6,608) I, DATA(1,I), DATA(2,I), CDATE(I), J, DATA(1,J), DATA(2,J), C
*DATA(J), IJ, DATA(1,IJ), DATA(2,IJ), CDATE(IJ), JJ, DATA(1,JJ), DATA(2,JJ)
168 *) , CDATE(IJJ), IJJ, DATA(1,IJJ), DATA(2,IJJ), CDATE(IJJ)
170
171 WRITE(6,609)
172 CALL PLOTR (IGCB,2,1,13)
173 CALL SETAR (IGCB,1,5)
174 CALL VIEWP (IGCB,30.,110.,20.,68.0)
175 CALL WINDOW (IGCB,-80.,80.,-160.00,160.0)
176 CALL FXD (IGCB,1)
177 WRITE(1,106)
178 READ (1,149) IDUM
179 IF (IDUM.EQ.2HYE) CALL LGRID (IGCB,-5.,10.,0.0,0.0,4.0,2.0,1.0)
180 CALL MOVE (IGCB,DATA(1,1),DATA(2,1))
181 DO 040 I=1,300,1
182 040 CALL DRAW (IGCB,DATA(1,I),DATA(2,I))
183 IF (IDUM.NE.2HYE) GOTO 050
184 CALL VIEWP (IGCB,0.,150.,0.,100.)
185 CALL WINDOW (IGCB,0.,150.,0.,100.)
186 CALL MOVE (IGCB,22.,15.)
187 CALL CPLOT(IGCB,-8.,0.,0)
188 CALL LABEL (IGCB)
189 WRITE(13,1301) DATA(1,320),DATA(2,319),IFILE
190 CALL MOVE (IGCB,22.,10.)
191 CALL CPLOT (IGCB,-8.,0.,0.)
192 CALL LABEL (IGCB)
193 WRITE (13,1302) DATA(1,318),DATA(2,318)
194 CALL MOVE (IGCB,18.0,20.)
195 CALL CPLOT (IGCB,-8.,0.,0.0)
196 CALL LDIR (IGCB,+1.57)
197 CALL LABEL (IGCB)
198 WRITE (13,1303)
199 050 CONTINUE
200 WRITE(1,107)
201 READ(1,149) IDUM
202 IF (IDUM.EQ.2HYE) GOTO 1
203 STOP 7777
204 END
205 REAL FUNCTION SCANR (LU,ICHAN,K)
206 .....
207 C Closes relay ICHAN on scanner LU and read the instrument
208 indicated by K.
209 Author: Robert N. Geopfarth
210 Date: February 31, 1979
211 Detailed program description is available in TXCO log; the
212 variables are:
213 LU ... LU# of desired scanner (8 or 15).
214 ICHAN ... Scanner channel (integer).
215 IC ... Scanner channel (ASCII).
216 K ... Instrument code (DVM = 1 / Counter = 2 ).
217 .....
218 C Closes scanner and reads DVM, counter.
219 *
220 101 FORMAT (A2)
221 801 FORMAT ("C")
222 1001 FORMAT ("T3T3")
223 1201 FORMAT ("T")
224 1501 FORMAT ("C")
225
226 WRITE ( 8, 801)
227 WRITE (15,1501)
228 IC = ICON(ICHAN,0)
229 WRITE (LU, 101) IC
230 GO TO (01,02) K
231
232 01 CALL TRIGR (10)
233 READ (10, *) DUM
234 CALL TRIGR (10)
235 READ (10, *) SCANR
236 GO TO 03
237
238

```

Figure C-4. Listing of Calibration Data Acquisition Program &KALIB.
(Continued on next page.)

```

0239      02 WRITE (12,1201)
0240      READ (12,*) SCNR
0241
0242      03 WRITE (14, 801)
0243      RETURN
0244      END
0245      INTEGER FUNCTION ICON(I,N)
0246      IC=I+N
0247      IF (IC.LT.10) GO TO 100
0248      CALL CODE
0249      WRITE(ICON,60)IC
0250      60  FORMAT(I2)
0251      RETURN
0252      100  ICON=IC+300608
0253      RETURN
0254      END

```

Figure C-4. Listing of Calibration Data Acquisition Program &KALIB.

APPENDIX D

DATA REDUCTION PROGRAMS &REST8 AND &REST9

The programs &REST8 and &REST9 are in principal the same and follow the same logic. They are used to approximate the Mach number--or X --and the pitch angle, ϕ , as functions of the two independent variables β and γ (see 4.5). The software used to work out the approximations is described explicitly in Ref. 6. Basis for the approximation is the data as shown in Table V. This data is stored as a 10 by 54 array in a data file ABNEW2 on cartridge 26. The data is read into a 10 by 54 array from file ABNEW2 by both programs. Since the approximation itself is carried out in external subroutines, the necessary variables are contained in a common block. &REST8 thus contains β (BETA), γ (GAMMA) and X (XVEL) while &REST9 contains β (BETA), γ (GAMMA) and PHI (pitch angle in radians). As approximations of different order are possible for both variables β and γ , the orders of the approximations are increased from one to six in a DO-loop for both variables, resulting in a total of 36 combinations.

For all combinations the set of coefficients is printed out and also an array (6,9) for all errors (see 4.5) resulting from this particular approximation. When the whole DO-loop is worked out, the operator has to decide what order of approximation he wants to use for the application of the

probes. In general lower order polynomials should be preferred against higher ones, although the latter promise the smaller overall error. The criterion for the decision should be the error distribution within a range of Mach number and pitch angle which will be the one of the most common application.

Once this decision has been made, the operator inputs the desired orders of polynomials. The corresponding coefficients are then recalculated and the operator is asked for a file name under which he wants to have these coefficients stored in a 7 by 7 array.

As programs &REST8 and &REST9 are in principal identical, only one flow chart (Fig. D-1) is given, and a listing of program &REST9 is given in (Fig. D-2).

Labeled common blocks:

<u>Common block identifier</u>		<u>Variable</u>
MATRX		A, B
SUMME		BETA, GAMMA, XVEL (or PHI)

<u>Variables</u>	<u>Type</u>	<u>Description</u>
A(49,49)	Real	System matrix used for the 3-D approximation of XVEL (or PHI) as function of BETA and GAMMA (see Ref. 6)
B(49)	Real	Right hand side vector of 3-D approximation (see Ref. 6)
BETA(16,16)	Real	Beta--pressure coefficient
COEFF(7,7)	Real	Approximation coefficients array

<u>Variables</u>	<u>Type</u>	<u>Description</u>
D(10,54)	Real	Calibration data array
GAMMA	Real	Gamma--pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file
NMACH	Real	Number of different Mach number settings during the calibration
NPITCH	Real	Number of different pitch angle settings during the calibration
PHI(16,16)	Real	Array containing the actual pitch angle settings during the calibration
PI	Real	3.14593
R(16)	Real	Array containing the individual errors between calibration data and calculated values
SUM	Real	Calculated value of XVEL or PHI (depending on program)
XVEL(16,16)	Real	Array containing the actual Mach number (X) settings during the calibration

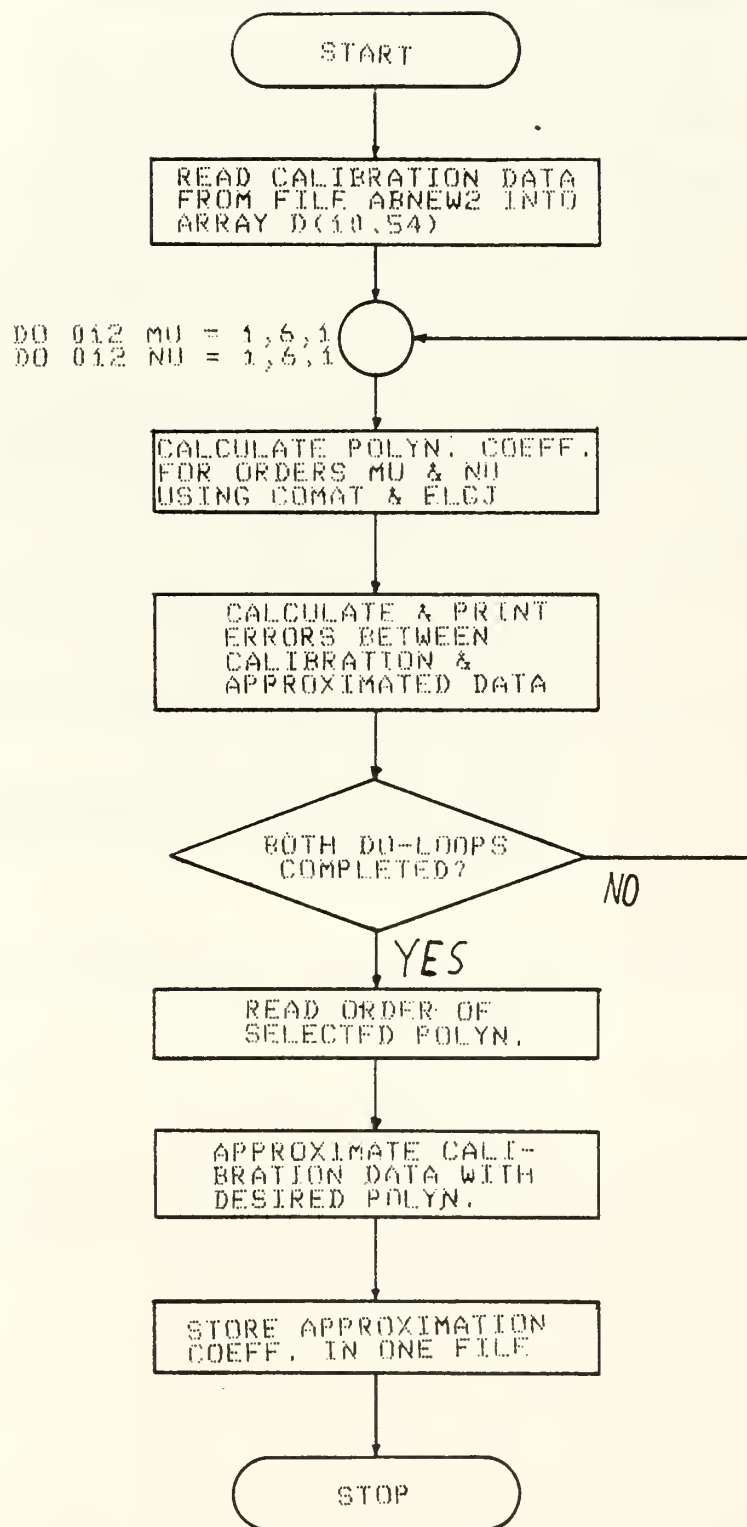


Figure D-1. Flow Chart of Data Reduction Program & REST 8/9

&REST9 T=00004 IS ON CR00026 USING 00024 BLKS R=0000

```

0001 FTN4,L
0002 PROGRAM REST9 (3,99)
0003 .....
0004 .
0005 . This is program REST9 I
0006 .
0007 . It reads file ARNEW2 (26) which contains calibration data from
0008 . the new A- and H-probe ( 0.062" o.d. screen with holes).
0009 . It then approximates the pitchangle Phi as a function of
0010 . beta and gamma by different order of polynomials .
0011 . The results of all approximations are printed for evaluation
0012 . purposes, but only one set of coefficients is stored.
0013 . The software used for the polynomial approximation is
0014 . available in the Turbopropulsion Laboratory Binary Library
0015 . (TPLBL). See NPS67-80-001CR for further reference.
0016 .
0017 .
0018 .
0019 COMMON / MATRX / A,B
0020 COMMON / SUMME / BETA,GAMMA,PHI
0021 REAL A(49,49),B(49),COEFF(7,7),D(10,54)
0022 INTEGER IDCBS(144),IFILE(3),ISIZE(2)
0023 REAL BETA(16,16),GAMMA(16,16),PHI(16,16)
0024 REAL R(16)
0025 DATA PI /3.141593/
0026 DATA IFILE /2HAB,2HNE,2HW2/
0027 DATA ISECU /0/
0028 DATA ICR /26/
0029 DATA ITYPE /1/
0030 DATA ISIZE /3,128/
0031 DATA IDCBS /144/
0032 101 FORMAT (SELECT SET OF COEFFICIENTS FOR BEST RESULTS I"/" ENTER M
0033 *ORDER AND NORDER NOW :")
0034 149 FORMAT ("((3A2)))
0035 601 FORMAT (///" COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FI
0036 *LE : "3A2/)
0037 602 FORMAT ((3X,10(11X,I2)))
0038 603 FORMAT (1X,I2,7(2X,F11.6))
0039 604 FORMAT (///" ERRORS AT EACH POINT (DEGREES)"/)
0040 605 FORMAT ((3X,16(6X,I2)))
0041 606 FORMAT (1X,I2,16(1X,F7.3)/3(3X,16(1X,F7.3)/))
0042 1111 FORMAT ( " STATEMENT # "I4 " ERROR # "I4 " ENCOUNTERED I")
0043 LI = LOGCU(I)
0044 .....
0045 .
0046 . READ DATA FILE ARNEW2 FROM CARTRIDGE 26 INTO ARRAY D(10,54).
0047 .
0048 .
0049 CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)
0050 JJ = 1
0051 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0052 CALL READF (IDCB,IERR,D,1080,LEN,1)
0053 JJ = 2
0054 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0055 CALL CLOSE (IDCB,IERR,0)
0056 JJ = 3
0057 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0058
0059 IJ = 0
0060 DO 001 I = 1,6,1
0061 DO 001 J = 1,9,1
0062 IJ = IJ + 1
0063 IF (J .EQ. 6) D(4,IJ) = D(4,IJ) + 0.00001
0064 PHI (I,J) = D(4,IJ) * PI /180.0
0065 BETA (I,J) = D(8,IJ)
0066 001 GAMMA(I,J) = D(9,IJ)
0067
0068 NMACH = 6
0069 NPITCH = 9
0070
0071 002 CONTINUE
0072 .....
0073 .
0074 . CALCULATE CALIBRATION SURFACE COEFFICIENTS.
0075 .
0076 .
0077 .
0078 .

```

Figure D-2. Listing of Reduced Data Approximation Program &REST9. (Continued on next page.)

```

0079 C      IJI .....
0080      DO 011 MU = 1,6,1
0081      DO 011 NU = 1,6,1
0082      MORDER = MU
0083      NORDER = NU
0084
0085 003 CONTINUE
0086      DO 004 I = 1,7,1
0087      DO 004 J = 1,7,1
0088      004 COEFF(I,J) = 0.0
0089      M = MORDER+1
0090      N = NORDER+1
0091      CALL COMAT (A,B,M,N,NMACH,NPITCH)
0092      NEQUS = M*N
0093      CALL ELGJ (NEQUS)
0094      I1 = 0
0095      DO 005 I = 1,M,1
0096      DO 005 J = 1,N,1
0097      I1 = I+1
0098 005 COEFF(I,J) = B(I1)
0099      IF ( IJI .NE. 1 ) GOTO 006
0100      IFILE(1) = 2HMI
0101      IFILE(2) = 2HST
0102      IFILE(3) = 2HFI
0103      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
0104      JJ = 4
0105      IF ( IERR .GT. 0 ) WRITE (LI,1111) JJ,IERR
0106      CALL OPEN (IDCB,IERR,IFILE,IOPFN,ISECU,ICR,IDCBS)
0107      JJ = 5
0108      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0109      CALL WRITF (IDCB,IERR,COEFF,98)
0110      JJ = 6
0111      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0112      CALL CLOSE (IDCB,IERR,0)
0113      JJ = 7
0114      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0115      WRITE (6,601) IFILE
0116 006 CONTINUE
0117      WRITE (6,602) (J,J=1,N,1)
0118      DO 007 I=1,M,1
0119 007 WRITE (6,603) I,(COEFF(I,J),J=1,N,1)
0120      WRITE (6,602) (J,J=1,N,1)
0121
0122 CCCCC .....
0123 : CALCULATE ERRORS FOR ALL MACHNUMBER PITCHANGLE COMBINATIONS. :
0124 :
0125 :
0126 .....
0127
0128      WRITE (6,604)
0129      WRITE (6,605) (J,J=1,NPITCH,1)
0130      DO 010 I = 1,NMACH,1
0131      DO 009 J = 1,NPITCH,1
0132      SUM = 0.
0133      DO 008 I1 = 1,M,1
0134      DO 008 J1 = 1,N,1
0135      SUM=SUM+(COEFF(I1,J1)*GAMMA(I,J)**(J1-1))*BETA (I,J)**(I1-1)
0136      009 R(J) = (PHI(I,J) - SUM) * 180.0 / PI
0137 010 WRITE (6,606) I,(R(J),J=1,NPITCH,1)
0138      WRITE (6,605) (J,J=1,NPITCH,1)
0139
0140      IF (IJI .EQ. 1 ) GOTO 012
0141
0142 011 CONTINUE
0143      WRITE (LI,101)
0144      READ (LI,*) MORDER,NORDER
0145      IJI = 1
0146      GOTO 003
0147 012 STOP 7777
0148      END

```

Figure D-2. Listing of Reduced Data Approximation Program &REST9.

APPENDIX E
DATA EVALUATION PROGRAM &EVALU

As described in 5.1, program &EVALU simulates a case in which calibration data is treated as actual test data--as far as possible. From this data flow quantities of Mach number and pitch angle are derived using the whole data reduction method, and compared with the known actual values.

The program is set up to perform this comparison for all given Mach number/pitch angle combinations. However, since the process is rather extensive and time-consuming, the procedure is actually only worked out for a limited range of calibration settings.

First of all the program reads the sets of coefficients for the Mach number and pitch angle approximations (as generated in &REST8 and &REST9) into two arrays. In a loop corresponding calibration data of the "A" and "B" probes for one Mach number/pitch angle combination is read at a time. This data is read into two data arrays (ADATA(2,320) and BDATA(2,320)). For nine defined yaw angles ($\pm 65^\circ$, $\pm 45^\circ$, $\pm 30^\circ$, $\pm 15^\circ$, 0°) the program searches for given yaw angles which are closest to the defined ones and averages four yaw angles bigger and four smaller than the one found as well as it averages the corresponding pressure values. This results in nine single pairs of PA values and yaw angles. The

B probe "data acquisition" is handled differently. For a range of yaw angle smaller than the whole calibration range the output of the B probe p_B is approximated with a sixth order polynomial as a function of yaw angle. For nine specific values of yaw ($\pm 30^\circ$, $\pm 22.5^\circ$, $\pm 15^\circ$, $\pm 7.5^\circ$, 0°) corresponding pressure values p_B are calculated using the derived polynomial.

These data arrays PA(9)/YAWA(9) and PB(9)/YAWB(9) are equivalent to the data acquired in a test. They are again approximated and the pressure values PAMAX, PSA and PBMAX are calculated. The data reduction procedure as outlined in 4.5 is applied to these values and the Mach number (or X) and pitch angle are derived. Since the yaw angle is always adjusted to zero when aligned with the flow in the freejet, the yaw angle should always turn out to be zero. However, the program offers the possibility to artificially superimpose a different yaw angle in that the given relationships $p_A = P_A(\alpha)$ and $p_B = P_B(\alpha)$ are shifted to $p_A = P_A(\alpha + \Delta\alpha)$ and $p_B = P_B(\alpha + \Delta\alpha)$, where $\Delta\alpha$ is the "artificial" yaw angle. The quality of the flow quantity calculations is expressed in errors of Mach number, pitch angle and yaw angle as described in 5.1. The necessary error values are printed out and the loop is continued. Figure E-1 gives a flow chart of the program while Fig. E-2 contains a listing.

Labeled Common Block:

Common block identifier:
DTA2

Variable:
X1, Y

<u>Variable</u>	<u>Type</u>	<u>Description</u>
AAO	Real	Flow yaw angle derived from A probe
ABO	Real	Flow yaw angle derived from B probe
ADATA(2,320)	Real	Array to contain the A probe data
AFILE(3)	Integer	Array to contain the file name for A probe data
ASL	Real	Left hand side yaw angle of A probe output
ASR	Real	Right hand side yaw angle of A probe output
BDATA(2,320)	Real	Array to contain the B probe data
BFILE(3)	Integer	Array to contain the file name for B probe data
COEF(7)	Real	Array to contain coefficients from 2-D approximations
COEUX(7,7)	Real	Array containing the coefficients of the 3-D approximation for the velocity
COEUP(7,7)	Real	Array containing the coefficients of the 3-D approximation for the pitch angle
CPAMAX	Real	Maximum pressure coefficient A probe
CPBMAX	Real	Maximum pressure coefficient B probe
DP	Real	Pressure difference for two pressure values corresponding to two yaw angles which are separated by DX
DPX	Real	First derivative of the function $p_A(\alpha) - p_A(\alpha - \Delta\alpha)$
DX	Real	Given spread in yaw angle between PSAL and PSAR

<u>Variable</u>	<u>Type</u>	<u>Description</u>
ERPHI	Real	Error between measured and calculated pitch angle
ERXVEL	Real	Error between measured and calculated Mach number (Xvel rsp.)
ERYAW	Real	Error between measured and calculated yaw angle
GAMMA	Real	Pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IFILE(3)	Integer	Array containing file name
IL	Integer	Total number of words read from data file (two words for one value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
ICLR(3)	Integer	Command to clear line above cursor
NOLF	Integer	No line feed command
NOCR	Integer	No carriage return command
PA(9)	Real	Array for A probe pressure values
PAMAX	Real	Maximum pressure of A probe
PB(9)	Real	Array for B probe pressure values
PBMAX	Real	Maximum pressure of B probe
PHI	Real	Pitch angle (calculated)
PHIME	Real	Pitch angle (measured)
PSA	Real	Static pressure equivalent of A probe
PSAL	Real	Pressure reading of A probe for a yaw angle 63° to the left of the flow aligned yaw angle

<u>Variable</u>	<u>Type</u>	<u>Description</u>
PSAR	Real	Pressure reading of A probe for a yaw angle 63° to the right of the flow aligned yaw angle
PSTAT	Real	Static pressure
PTOTAL	Real	Total pressure
P1-P8	Real	A probe pressure values in the vicinity of a given yaw angle giving the basis to find an average pressure value for the corresponding yaw angle
XVEL	Real	Mach number equivalent dimensionless speed
XVELME	Real	Measured XVEL
X0	Real	Starting value for the iteration to find PSAL and PSAR
X1(256)	Real	Data array for 2-D approximations
Y(256)	Real	Data array for 2-D approximations
YAWA(9)	Real	Array containing A probe yaw angles
YAWB(9)	Real	Array containing B probe yaw angles
YAWOFF	Real	Superimposed yaw angle offset to simulate yaw angles different from 0° .
Y1-Y8	Real	A probe yaw angles in the vicinity of a given yaw angle equivalent to P1-P8.

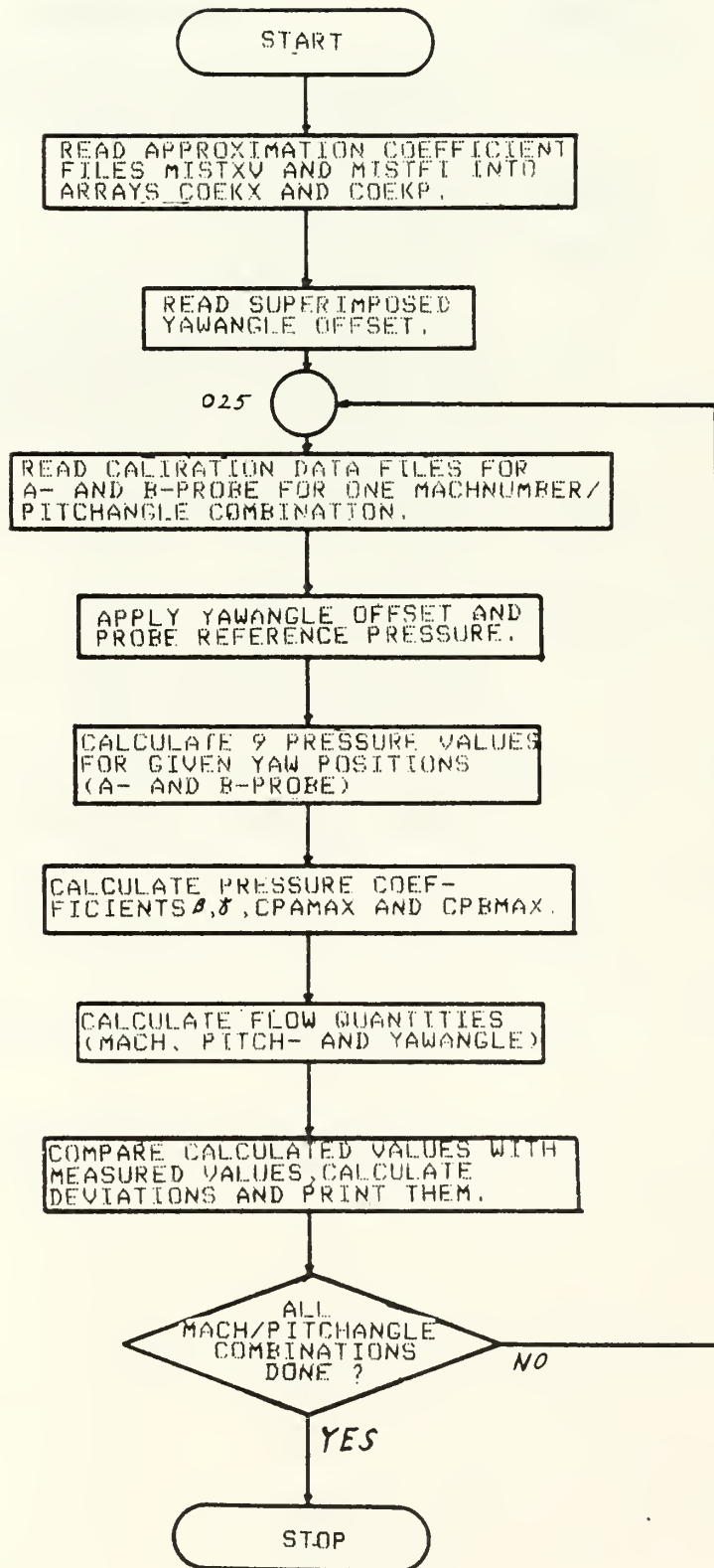


Figure E-1. Flow Chart of Data Evaluation Program &EVALU.

&EVALU T=00004 IS ON CR00026 USING 00051 2LKS R=0000

```

0001 FTN4,L
0002 PROGRAM EVALU (3,99)
0003
0004 .....
0005 THIS IS PROGRAM E V A L U (a t e) !
0006 .....
0007 IT CAN TREAT THE RAW DATA FROM THE A- AND B-PROBE CALI-
0008 BRATION LIKE ACTUAL TEST DATA !
0009 .....
0010 .....
0011 .....
0012 COMMON / DIA2 / X1,Y
0013 INTEGER IDCBS(144),IFILE(3),ISIZE(2),NOLF,NOCR(2),ICLR(3)
0014 INTEGER AFIL(3),BFIL(3)
0015 REAL ADATA(2,320),BDATA(2,320),X1(256),Y(256),COEF(7)
0016 REAL COEKX(7,7),COEKP(7,7)
0017 REAL PA(9),PB(9),YAWA(9),YAWB(9)
0018 DATA ISIZE(1) / 10/
0019 DATA ISIZE(2) / 128/
0020 DATA ITYPE / 1/
0021 DATA IDCBS / 144/
0022 DATA IL / 1280/
0023 DATA NOLF / 006537B/
0024 DATA NOCR / 000033B,040433B/
0025 DATA ICLR / 015524B,015515B,006537B/
0026 148 FORMAT ( " DO YOU WANT AN OUTPUT OF THE CALIBRATION COEFFICIENTS?"
0027 * " ENTER YES IF SO OR ANYTHING ELSE IF NOT!" )
0028 149 FORMAT ((3A2))
0029 150 FORMAT ( " ENTER FILE ( ) FOR X APPROXIMATION!" /
0030 * " DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!" /
0031 * " : "A2)
0032 151 FORMAT (3A2,1X,I2,1X,I2)
0033 152 FORMAT ( " THE DATA READ FROM FILE "3A2" ARE" / )
0034 153 FORMAT ( " I 7 J "I3,5I12)
0035 154 FORMAT ( " I3,7(1X,F11.6))
0036 155 FORMAT ( " ENTER FILE (SIFP ) FOR PHI APPROXIMATION!" /
0037 * " DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!" /
0038 * "SIFP : "A2)
0039 156 FORMAT ( " ENTER THE OFFSET OF THE YAW ANGLE IN DEGREES !" )
0040 157 FORMAT ( " RESULTS FROM THE A-B SYSTEM: " // 10X " CALCULATION: " 15X " MEASU
0041 * REMENT: " 12X " ERRORS " 6X " XVEL " 5X " PITCH " 7X " YAW " 6X " XVEL " 5X " PITCH " 6X " XV
0042 * EL " 5X " PITCH " 7X " YAW " 3X " YAW FROM A PROBE " // )
0043 158 FORMAT (1X(3A2))
0044 159 FORMAT ( " R A W D A T A : " / " * A - KULITE B - KULITE " 7X " YAW A
0045 * " 7X " YAW B " )
0046 160 FORMAT (13,4(2X,F10.5))
0047 161 FORMAT ( " A-PROBE APPROXIMATION RESULTS : YAW = " 7(5X,F9.2)/16X " PR
0048 * ESSURE (INCH H20) = " 3(3X,F11.6)/29X " CPAMAX = " F8.4 / )
0049 162 FORMAT ( " B-PROBE APPROXIMATION RESULTS : YAW0 = " F5.1 " PRESSURE
0050 * (INCH H20) = " F5.2 / )
0051 163 FORMAT (1X,F9.4,2(3X,F7.2),1X,F9.4,3X,F7.2,1X,F9.4,3(3X,F7.2))
0052 601 FORMAT ( " I / J " I12,6I16)
0053 602 FORMAT ( " I3,7(1X,F15.6))
0054 603 FORMAT ( " ARTIFICIAL YAW ANGLE OFFSET IS : " I3 " DEGREES " // )
0055 604 FORMAT ( / )
0056 1111 FORMAT ( " STATEMENT * = " I3 " ERROR * = " I3 " ENCOUNTERED!" )
0057 LI = LOGLU (ISESSN)
0058 LO = 0
0059 WRITE (LI,148)
0060 READ (LI,149) IPRIN1
0061 .....
0062 READ FILE FROM DISC INTO ARRAY COEKX(7,7).
0063 .....
0064 .....
0065 .....
0066 WRITE (LI,150) NOLF
0067 READ (LI,151) IFILE,ISECU,ICR
0068 WRITE (LI,149) (ICLR,II = 1,3)
0069 CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)
0070 JJ = 1
0071 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0072 CALL READF (IDCB,IERR,COEKX,98,LEN,1)
0073 JJ = 2
0074 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0075 CALL CLOSE (IDCB,IERR,0)
0076 JJ = 3
0077 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0078 IF (IPRIN1 .NE. 2HYE) GOTO 010

```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.
(Continued on next page.)

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.
(Continued on next page.)

```

0159 CALL READF (IDCR,IERR,BDATA,LCLEN,1)
0160 JJ = 11
0161 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0162 CALL CLOSE (IDCR,IERR,0)
0163 JJ = 12
0164 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0165
0166 DO 030 I = 1,300,1
0167 ADATA (1,I) = ADATA (1,I) + YAWOFF
0168 BDATA (1,I) = BDATA (1,I) + YAWOFF
0169 ADATA (2,I) = ADATA (2,I) + BDATA (1,319)
0170 BDATA (2,I) = BDATA (2,I) + BDATA (1,319)
030  I1 = 0
0171 DO 055 J = -60,60,15
0172 J1 = J
0173 IJ = J / 2
0174 IF ( J .EQ. -60 ) J1 = -65
0175 IF ( J .EQ. 60 ) J1 = 65
0176 I1 = I1 + 1
0177 DO 035 I = 1,150,1
0178 IF (ADATA(1,I) .LT. J1 ) GOTO 035
0179 Y1 = ADATA(1,I-2)
0180 P1 = ADATA(2,I-2)
0181 Y2 = ADATA(1,I-1)
0182 P2 = ADATA(2,I-1)
0183 Y3 = ADATA(1,I)
0184 P3 = ADATA(2,I)
0185 Y4 = ADATA(1,I+1)
0186 P4 = ADATA(2,I+1)
0187 GOTO 040
0188 035 CONTINUE
0189 DO 045 I = 151,300,1
0190 IF (ADATA(1,I) .GT. J1 ) GOTO 045
0191 Y5 = ADATA(1,I-2)
0192 P5 = ADATA(2,I-2)
0193 Y6 = ADATA(1,I-1)
0194 P6 = ADATA(2,I-1)
0195 Y7 = ADATA(1,I)
0196 P7 = ADATA(2,I)
0197 Y8 = ADATA(1,I+1)
0198 P8 = ADATA(2,I+1)
0199 GOTO 050
0200 045 CONTINUE
0201 050 X1(1) = Y1
0202 X1(2) = Y2
0203 X1(3) = Y3
0204 X1(4) = Y4
0205 X1(5) = Y5
0206 X1(6) = Y6
0207 X1(7) = Y7
0208 X1(8) = Y8
0209 Y (1) = P1
0210 Y (2) = P2
0211 Y (3) = P3
0212 Y (4) = P4
0213 Y (5) = P5
0214 Y (6) = P6
0215 Y (7) = P7
0216 Y (8) = P8
0217 YAWB(I1) = (Y1+Y2+Y3+Y4+Y5+Y6+Y7+Y8) / 8
0218 PA (I1) = (P1+P2+P3+P4+P5+P6+P7+P8) / 8
0219 DO 060 I = 26,125,1
0220 J = I - 25
0221 X1(J) = BDATA(1,I)
0222 Y (J) = BDATA(2,I)
0223 DO 065 I = 176,275,1
0224 J = I - 75
0225 X1(J) = BDATA(1,I)
0226 Y (J) = BDATA(2,I)
0227 065 NPNTS = 200
0228 CALL MAT2 (NPNTS,7,COEF,-1)
0229
0230 DO 070 I = 1,9,1
0231 YAWB(I) = 25 * ( I - 5 )
0232 070 PB (I) = FNP(6,COEF,YAWB(I))
0233
0234 WRITE (LI,159)
0235 DO 075 I = 1,9,1
0236
0237
0238

```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.
(Continued on next page.)

```

0239 075 WRITE (LI,160) I,PA(I),PB(I),YAWA(I),YAWB(I)
0240
0241 PBARO = (ADATA(2,319) + BDATA(2,319)) / 2
0242 PSTAT = PBARO * 13.585
0243 PTOTAL = ((ADATA(2,318) + BDATA(2,318)) / 2) + (PBARO * 13.585)
0244 XVELME = SQRT ( 1 - (PTOTAL/PSTAT) ) ** (-0.2857) )
0245 PHIME = ADATA(1,320)
0246 DO 080 I = 1,9,1
0247 X1(I) = YAWA(I)
0248 Y(I) = PA(I) + (PBARO * 13.585)
0249 CALL MAT2 (9,5,COEF,-4)
0250
0251 .....
0252 : FIND MAX. OUTPUT OF A PROBE.
0253 : .....
0254 C
0255 DX = 126.0
0256 DP = -70.0
0257 085 X0 = (FNP(4,COEF,X0)-FNP(4,COEF,(X0+DX)))
0258 IF (ABS(DP) .LT. 0.0001) GOTO 090
0259 DPX = -2.*COEF(3)*DX-6.*COEF(4)*X0*DX-3.*COEF(4)*DX*DX-
0260 * 12.*COEF(5)*X0*X0*DX-12.*COEF(5)*X0*DX*DX-4.*COEF(5)*DX**3
0261 X0 = X0 - DP / DPX
0262 GOTO 085
0263 090 ASL = X0
0264 ASR = X0 + DX
0265 AA0 = X0 + DX / 2.0
0266 PAMAX = FNP(4,COEF,AA0)
0267 PSAL = FNP(4,COEF,ASL)
0268 PSAR = FNP(4,COEF,ASR)
0269 PSA = (PSAL + PSAR) / 2.0
0270 PTOTAL = PAMAX
0271 BETA = (PAMAX - PSA) / PAMAX
0272 CPAMAX = (PAMAX - PSA) / (PTOTAL - PSA)
0273 IF (IPRINT .NE. 2HYE) GOTO 095
0274 WRITE (LI,161) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
0275 IF (LO .NE. 0) WRITE (LO,161) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
0276 095 CONTINUE
0277
0278 .....
0279 : APPROXIMATE B-PROBE PRESSURES.
0280 : .....
0281 C
0282 DO 100 I = 1,9,1
0283 X1(I) = YAWB(I)
0284 Y(I) = PB(I) + (PBARO * 13.585)
0285 100 CALL MAT2 (9,5,COEF,-4)
0286 X0 = 0.00
0287 DPX = FND(4,COEF,X0)
0288 IF (ABS(DPX) .LT. 0.00001) GOTO 115
0289 X0 = X0 - DPX / (2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
0290 GOTO 110
0291 115 AB0 = X0
0292 PRMAX = FNP(4,COEF,AB0)
0293 IF (IPRINT .NE. 2HYE) GOTO 120
0294 WRITE (LI,162) AB0,PRMAX
0295 IF (LO .NE. 0) WRITE (LO,162) AB0,PRMAX
0296 120 CONTINUE
0297 CPRMAX = (PRMAX - PSA) / (PTOTAL - PSA)
0298 GAMMA = (CPAMAX - CPRMAX) / CPAMAX
0299 XVEL = 0.0
0300 PHI = 0.0
0301 DO 125 I1 = 1,7,1
0302 DO 125 I2 = 1,7,1
0303 XVEL = XVEL + (COEKX(I1,I2) * GAMMA** (I2-1)) * BETA** (I1-1)
0304 PHI = PHI + (COEKX(I1,I2) * GAMMA** (I2-1)) * BETA** (I1-1)
0305 125 PHI = PHI * 180. / 3.14159
0306 ERXVEL = ((XVELME - XVEL) / XVEL) * 100.
0307 ERPHI = PHIME - PHI
0308 ERYAW = YAWOFF - AB0
0309 WRITE (LI,163) XVEL,PHI,AB0,XVELME,PHIME,ERXVEL,ERPHI,ERYAW,AA0
0310 IF (LO .NE. 0) WRITE (LO,163) XVEL,PHI,AB0,XVELME,PHIME,ERXVEL,ERPHI
0311 * ERYAW,AA0
0312 135 CONTINUE
0313 IF (IS .EQ. 55) GOTO 500
0314
0315 IF (IS .EQ. 10) GOTO 210
0316 IF (IS .EQ. 19) GOTO 220
0317 IF (IS .EQ. 28) GOTO 230
0318 IF (IS .EQ. 37) GOTO 240

```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.
(Continued on next page.)

```

0319 IF (IS .EQ. 46 ) GOTO 250
0320 GOTO 260
0321 210 AFILE(1) = 2HA3
0322 BFIL(1) = 2HB3
0323 IJI = IS - 9
0324 WRITE (LO,604)
0325 GOTO 260
0326 220 AFILE(1) = 2HA4
0327 BFIL(1) = 2HB4
0328 IJI = IS - 18
0329 WRITE (LO,604)
0330 GOTO 260
0331 230 AFILE(1) = 2HA5
0332 BFIL(1) = 2HB5
0333 IJI = IS - 27
0334 WRITE (LO,604)
0335 GOTO 260
0336 240 AFILE(1) = 2HA6
0337 BFIL(1) = 2HB6
0338 IJI = IS - 36
0339 WRITE (LO,604)
0340 GOTO 260
0341 250 AFILE(1) = 2HA7
0342 BFIL(1) = 2HB7
0343 IJI = IS - 45
0344 WRITE (LO,604)
0345 GOTO 260
0346 260 IF ( IJI .EQ. 1 ) GOTO 300
0347 IF ( IJI .EQ. 2 ) GOTO 310
0348 IF ( IJI .EQ. 3 ) GOTO 320
0349 IF ( IJI .EQ. 4 ) GOTO 330
0350 IF ( IJI .EQ. 5 ) GOTO 340
0351 IF ( IJI .EQ. 6 ) GOTO 350
0352 IF ( IJI .EQ. 7 ) GOTO 360
0353 IF ( IJI .EQ. 8 ) GOTO 370
0354 IF ( IJI .EQ. 9 ) GOTO 380
0355 AFIL(3) = 2H25
0356 AFIL(2) = 2HKP
0357 GOTO 400
0358 310 AFIL(3) = 2H20
0359 AFIL(2) = 2HKP
0360 GOTO 400
0361 320 AFIL(3) = 2H15
0362 AFIL(2) = 2HKP
0363 GOTO 400
0364 330 AFIL(3) = 2H10
0365 AFIL(2) = 2HKP
0366 GOTO 400
0367 340 AFIL(3) = 2H05
0368 AFIL(2) = 2HKP
0369 GOTO 400
0370 350 AFIL(3) = 2H00
0371 AFIL(2) = 2HKP
0372 GOTO 400
0373 360 AFIL(3) = 2H05
0374 AFIL(2) = 2HKN
0375 GOTO 400
0376 370 AFIL(3) = 2H10
0377 AFIL(2) = 2HKN
0378 GOTO 400
0379 380 AFIL(3) = 2H15
0380 AFIL(2) = 2HKN
0381 GOTO 400
0382 400 BFIL(2) = AFIL(2)
0383 BFIL(3) = AFIL(3)
0384 GOTO 025
0385 500 STOP 7777
0386 END
0387 REAL FUNCTION FNP(NORDER,COEFF,ZX)
0388 REAL COEFF(7)
0389 A1 = COEFF(NORDER+1)
0390 IF ( NORDER .EQ. 0 ) GOTO 02
0391 DO 01 I1 = 1,NORDER,1
0392 I = NORDER + 1 - I1
0393 A1 = COEFF(I)+ZX*A1
0394 01 FNP = A1
0395 RETURN
0396 END
0397 REAL FUNCTION FND(NORDER,COEFF,ZX)
0398 REAL COEFF(7)
0399 REAL COEFFD(6)
0400 DO 01 I1=1,NORDER,1
0401 COEFFD(I) = COEFF(I+1)*I
0402 A1 = COEFFD(NORDER)
0403 NORDR = NORDER - 1
0404 IF ( NORDR .EQ. 0 ) GOTO 03
0405 DO 02 I1 = 1,NORDR,1
0406 I = (NORDR + 1) - I1
0407 A1 = COEFFD(I)+ZX*A1
0408 02 FND = A1
0409 03 RETURN
0410 END

```

Figure E-2. Listing of Calibration Data Evaluation Program &EVALU.

APPENDIX F

CALIBRATION TEST PROGRAM TEST

Chapter 5.2 describes the test and the test procedure used to verify the quality of the calibration in a freejet experiment. Although this experiment lacks the simulation of high frequency flow vector changes like those to be expected in its application, it seems to be the most useful check of the calibration itself and the data reduction procedure. While the set-up of the experiment and the data acquisition procedure were described in 5.2 already, details of computer program &TEST, which is used to perform the data acquisition and the data reduction, will be given herein.

Like program &EVALU, this program first reads the calibration coefficient files into two arrays. It then asks the operator to key in the barometric pressure in inches of mercury. The data acquisition itself is performed in a DO-loop, interactively with the operator. Both probes are set to nine different yaw angles and data samples are recorded. The actual pressure and yaw angle values which are used are the averages of 30 single samples each, in order to exclude any influence of some flow irregularities. Once the data is taken, the data acquisition system is released from the HP 21-MX computer control and the data reduction is started.

The nine pressure values of the A-probe are approximated with a fourth-order polynomial as a function of the yaw angle. From this approximated curve pressure values PSAL, PSAR and PAMAX are derived which are used to calculate CPAMAX and BETA. The output of the B probe is approximated the same way and the pressure PBMAX is calculated from this curve. Using PBMAX and the results of the A probe, CPBMAX and GAMMA are established. The coefficients BETA and GAMMA alone are used to derive values of Mach number (or X) and pitch angle (ϕ). The yaw angle which corresponds to the pressure value PBMAX is assumed to be the flow yaw angle. It should be close to zero since the probes are aligned with the freejet for a zero yaw angle, unless an "artificial" yaw angle has been superimposed on them as described in 5.2

The calculated values are compared to those the freejet was adjusted to. In 5.2 the results of these comparisons were demonstrated already.

Labeled common block:

Common block identifier: Variable:

DTA2 X1,Y

<u>Variable</u>	<u>Type</u>	<u>Description</u>
AAO	Real	Flow yaw angle derived from A probe
ABO	Real	Flow yaw angle derived from B probe
AKULIT	Real	Average value of 30 A probe pressure samples

<u>Variable</u>	<u>Type</u>	<u>Description</u>
APRESS	Real	Single sample value of A probe pressure reading
ASL	Real	Left-hand side yaw angle of A probe output
ASR	Real	Right-hand side yaw angle of A probe output
BKULIT	Real	Average value of 30 B probe pressure samples
BPRESS	Real	Single sample value of B probe pressure reading
COEF(7)	Real	Array to contain coefficients from 2-D approximations
COEUX(7,7)	Real	Array containing the coefficients of the 3-D approximation for the velocity
COEUP(7,7)	Real	Array containing the coefficients of the 3-D approximation for the pitch angle
CPAMAX	Real	Maximum pressure coefficient A probe
CPBMAX	Real	Maximum pressure coefficient B probe
DP	Real	Pressure difference for two pressure values corresponding to two yaw angles which are separated by DX
DPX	Real	First derivative of the function $P_A(\alpha) - P_A(\alpha - \Delta\alpha)$
DX	Real	Given spread in yaw angle between PSAL and PSAR
GAMMA	Real	Pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IDCBS	Integer	Control block length (of IDCB)
IFILE(3)	Integer	Array containing file name

<u>Variable</u>	<u>Type</u>	<u>Description</u>
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
ICLR(3)	Integer	Command to clear line above cursor
NOLF	Integer	No line feed command
PA(9)	Real	Array for A probe pressure values
PAMAX	Real	Maximum pressure of A probe
PB(9)	Real	Array for B probe pressure values
PBARO	Real	Barometric pressure inches of mercury
PBMAX	Real	Maximum pressure of B probe
PHI	Real	Pitch angle (calculated)
PSA	Real	Static pressure equivalent of A probe
PSAL	Real	Pressure reading of A probe for a yaw angle 63° to the left of the flow aligned yaw angle
PSAR	Real	Pressure reading of A probe for a yaw angle 63° to the right of the flow aligned yaw angle
PTOTAL	Real	Total pressure
XVEL	Real	Mach number equivalent dimensionless speed
X0	Real	Starting value for the iteration to find PSAL and PSAR
X1(256)	Real	Data array for 2-D approximations
Y(256)	Real	Data array for 2-D approximations
YAWANG	Real	Single sample of yaw angle reading
YAWKUL	Real	Average value of 30 yaw angle readings

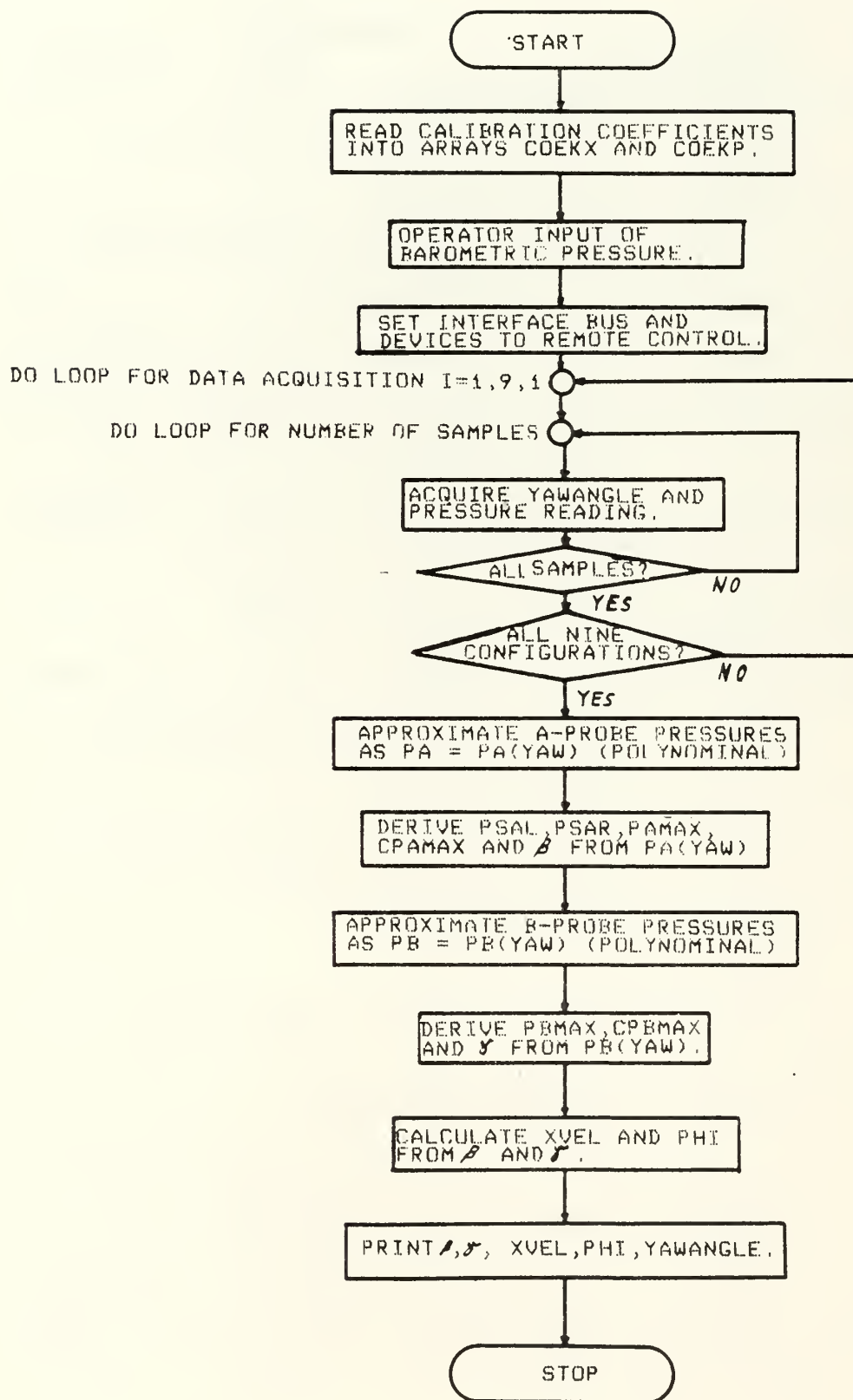


Figure F-1. Flow Chart of Calibration Evaluation Program &TEST.

%TEST T=00004 IS ON CR00026 USING 00055 BLKS R=0000

```

0001  FIN4,L
0002  PROGRAM TEST (3,99)
0003  .....
0004  THIS IS PROGRAM TEST FOR THE A-B PROBE SYSTEM.
0005  .....
0006  IT ACQUIRES DATA FROM THE A-B PROBES MOUNTED IN THE FREE-
0007  SET IN ORDER TO CHECK THE VALIDITY OF THE CALIBRATION.
0008  THE DATA IS NOT STORED, ONLY AN ONLINE OUTPUT IS AVAI-
0009  LABLE.
0010  .....
0011  .....
0012  .....
0013  .....
0014  COMMON
0015  / DTA2 / X1,Y
0016  REAL X1(256),Y(256)
0017  REAL COEF(7),COEKX(7,7),COEKP(7,7)
0018  REAL PA(9),PR(9),YAW(9)
0019  INTEGER IDCX(144),IFILE(3),ISIZE(2)
0020  INTEGER NOLF,ICLR(3)
0021  DATA IDCBS / 144 /
0022  DATA ITYPE / 1 /
0023  DATA ICLR / 015524B,015515B,006537B /
0024  DATA NOLFS / 006537B /
0025  101 FORMAT (" OUTPUT INPUT DATA TO ANY OTHER DEVICE? ENTER NO
0026  * OR LU$ 1/" "A2)
0027  102 FORMAT (" DO YOU WANT AN OUTPUT OF THE CALIBRATION COEFFICIENTS?"
0028  */* ENTER YES IF SO OR ANYTHING ELSE IF NOT!")
0029  103 FORMAT (" DO YOU WANT AN OUTPUT OF THE CONTROLL PARAMETERS?"/" KE
0030  *Y YES IF SO OR ANYTHING ELSE IF NOT!")
0031  104 FORMAT (/" THE DATA READ FROM FILE "3A2" ARE"/)
0032  105 FORMAT (" I / J "I3,5I12)
0033  106 FORMAT (" I / J "I12,6I16)
0034  107 FORMAT (" I3,7(1X,F15,6))
0035  108 FORMAT (" I / J "I12,6I16)
0036  109 FORMAT (" ENTER P BARO IN INCHES HG 1")
0037  110 FORMAT (/" R A W D A T A :"/" * A - KULITE B - KULITE"2X"YAW")
0038  111 FORMAT (" WHEN YOU ARE READY FOR YAW ANGLE # "I2" HIT CR 1")
0039  112 FORMAT (I3,3(2X,F10,5))
0040  113 FORMAT(" A-PROBE APPROXIMATION RESULTS : YAW = "3(5X,F9,2)/16X" PR
0041  *ESSURE (INCH H2O) = "3(3X,F11,6)/29X" CPAMAX = "F9,4/)
0042  114 FORMAT(/" B-PROBE APPROXIMATION RESULTS : YAWO = "F5,1" PRESSURE
0043  *(INCH H2O) = "F6,2/))
0044  115 FORMAT(" AVERAGE VALUE RESULTS FROM THE A-B SYSTEM: /"5X"BETA"4X"G
0045  *AHMA"5X"xvel"4X"Pitch"6X"Yaw"/3(F9,5),2(2X,F7,2))
0046  149 FORMAT ((3A2))
0047  150 FORMAT (I2)
0048  1111 FORMAT (" STATEMENT # "I4" ERROR # : "F12,2" DETECTED")
0049  1001 FORMAT ("FIR7M3A0H0I3")
0050  1501 FORMAT ("CA")
0051  LI = LOGLU(ISESSN)
0052  005 WRITE (LI,101) NOLF
0053  READ (LI,149) IDUM
0054  WRITE (LI,149) (ICLR,I=1,2)
0055  IF ( IDUM .EQ. 2HND ) GO TO 010
0056  CALL CODE
0057  READ (IDUM,150) LO
0058  IF ( LO .EQ. 1 ) GO TO 015
0059  IF ( LO .EQ. 6 ) GO TO 015
0060  IF ( LO .EQ. 18 ) GO TO 015
0061  GO TO 005
0062  010 LO = 0
0063  015 IF ( LO .EQ. LI ) LO = 0
0064  WRITE (LI,102)
0065  READ (LI,149) IPRIN1
0066  WRITE (LI,103)
0067  READ (LI,149) IPRINT
0068  .....
0069  .....
0070  READ FILE SIFX22 FROM DISC INTO ARRAY COEKX(7,7).
0071  .....
0072  .....
0073  IFILE(1) = 2H51
0074  IFILE(2) = 2HFX
0075  IFILE(3) = 2H43
0076  ISECU = 00
0077  ICR = 26
0078  CALL OPEN (IDCR,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)

```

Figure F-2. Listing of Program to Test the Quality of the Calibration: %TEST.
(Continued on next page.)

```

0079      JJ = 1
0080      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0081      CALL READF (IDCB,IERR,COEKX,98,LEN,1)
0082      JJ = 2
0083      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0084      CALL CLOSE (IDCB,IERR,0)
0085      JJ = 3
0086      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0087      IF (IPRIN1 .NE. 2HYES) GOTO 025
0088      .....
0089      : OUTPUT INPUT DATA.
0090      :
0091      :
0092      :
0093      WRITE (LI,104) IFILE
0094      IF ( LO .NE. 0 ) WRITE (LO,104) IFILE
0095      WRITE (LI,105) (I1,I1=1,7)
0096      IF ( LO .NE. 0 ) WRITE (LO,106) (I1,I1=1,7)
0097      DO 020 I1=1,7,1
0098      IF ( LO .NE. 0 ) WRITE (LO,107) I1,(COEKX(I1,J1),J1=1,7,1)
0099      020 WRITE (LI,108) I1,(COEKX(I1,J1),J1=1,7,1)
0100      .....
0101      : READ FILE SIFP22 FROM DISC INTO ARRAY COEKP(7,7).
0102      :
0103      :
0104      :
0105      025 IFILE(1) = 2HSI
0106      IFILE(2) = 2HFP
0107      IFILE(3) = 2H43
0108      CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)
0109      JJ = 4
0110      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0111      CALL READF (IDCB,IERR,COEKP,98,LEN,1)
0112      JJ = 5
0113      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0114      CALL CLOSE (IDCB,IERR,0)
0115      JJ = 6
0116      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0117      IF (IPRIN1 .NE. 2HYES) GOTO 035
0118      .....
0119      : OUTPUT INPUT DATA.
0120      :
0121      :
0122      :
0123      WRITE (LI,104) IFILE
0124      IF ( LO .NE. 0 ) WRITE (LO,104) IFILE
0125      WRITE (LI,105) (I1,I1=1,7)
0126      IF ( LO .NE. 0 ) WRITE (LO,106) (I1,I1=1,7)
0127      DO 030 I1=1,7,1
0128      IF ( LO .NE. 0 ) WRITE (LO,107) I1,(COEKP(I1,J1),J1=1,7,1)
0129      030 WRITE (LI,108) I1,(COEKP(I1,J1),J1=1,7,1)
0130      035 CONTINUE
0131      .....
0132      : THE DATA ACQUISITION SHALL BE PERFORMED NOW !
0133      :
0134      :
0135      :
0136      :
0137      WRITE (LI,109)
0138      READ (LI,*) PRARD
0139      CALL ABRT (7,2)
0140      CALL RMOTE (10)
0141      CALL RMOTE (15)
0142      .....
0143      WRITE (10,1001)
0144      WRITE (15,1501)
0145      .....
0146      WRITE (LO,110)
0147      DO 050 I = 1,9,1
0148      040 WRITE (LI,111) I
0149      READ (LI,149) IDUM
0150      IF ( IDUM .NE. 2H ) GOTO 040
0151      AKULIT = 0.0
0152      YAWKUL = 0.0
0153      BKULIT = 0.0
0154      DO 045 J = 1,30,1
0155      YAWANG = SCANR (15,22,01)
0156      BPRESS = SCANR (15,33,01)
0157      APRESS = SCANR (15,34,01)
0158      AKULIT = AKULIT + APRESS

```

Figure F-2. Listing of Program to Test the Quality of the Calibration: &TF
(Continued on next page.)


```

0159 YAWKUL = YAWKUL + YAWANG
0160 BKULIT = BKULIT + BPRESS
0161 PA(I) = AKULIT / 30
0162 PB(I) = BKULIT / 30
0163 YAW(I) = YAWKUL / 30
0164 050 WRITE (LD,112) I,PA(I),PB(I),YAW(I)
0165 CALL CLEAR (7,1)
0166 CALL LOCL (7)
0167
0168 .....
0169 : START DATA REDUCTION.
0170 :
0171 .....
0172 DO 055 I = 1,9,1
0173 X1(I) = YAW(I) * 10000
0174 Y(I) = (PA(I) * 10000) + (PBARD * 13.585)
0175 055 CALL MAT2(9,5,COEF,-4)
0176 .....
0177 : FIND MAX. OUTPUT OF A PROBE.
0178 :
0179 .....
0180 DX = 126.0
0181 X0 = -70.0
0182 DP = (FNP(4,COEF,X0) - FNP(4,COEF,(X0+DX)))
0183 060 IF (ABS(DP) .LT. 0.0001) GOTO 065
0184 DPX = -2.0*COEF(3)*DX-6.0*COEF(4)*X0*DX-3.0*COEF(4)*DX*DX-
0185 * 12.0*COEF(5)*X0*X0*DX-12*COEF(5)*X0*DX*DX-4.0*COEF(5)*DX**3
0186 X0 = X0 - DP / DPX
0187 GOTO 060
0188 065 ASL = X0
0189 ASR = X0 + DX
0190 AA0 = X0 + DX / 2.0
0191 PAMAX = FNP(4,COEF,AA0)
0192 PSAL = FNP(4,COEF,ASL)
0193 PSAR = FNP(4,COEF,ASR)
0194 PSA = (PSAL + PSAR) / 2.0
0195 PTOTAL = PAMAX
0196 BETA = (PAMAX - PSA) / PAMAX
0197 CPAMAX = (PAMAX - PSA) / (PTOTAL - PSA)
0198 IF (IPRINT.NE.2HYE) GOTO 070
0199 WRITE (LI,113) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
0200 IF (LD.NE.0) WRITE (LD,113) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
0201 070 CONTINUE
0202 .....
0203 : APPROXIMATE 8 PROBE PRESSURES.
0204 :
0205 .....
0206 DO 075 I = 1,9,1
0207 X1(I) = YAW(I) * 10000
0208 Y(I) = (PB(I) * 10000) + (PHARD * 13.585)
0209 075 CALL MAT2(9,5,COEF,-4)
0210 X0 = 0.00
0211 DPX = FND(4,COEF,X0)
0212 IF (ABS(DPX) .LT. 0.00001) GOTO 085
0213 X0 = X0 - DPX / (2*COEF(3) + 8*COEF(4)*X0 + 12*COEF(5)*X0*X0)
0214 GOTO 080
0215 080 AR0 = X0
0216 PRMAX = FNP(4,COEF,AR0)
0217 IF (IPRINT.NE.2HYE) GOTO 090
0218 WRITE (LI,114) AR0,PRMAX
0219 IF (LD.NE.0) WRITE (LD,114) AR0,PRMAX
0220 090 CONTINUE
0221 CPBMAX = (PRMAX - PSA) / (PTOTAL - PSA)
0222 GAMMA = (CPAMAX - CPBMAX) / CPAMAX
0223 XVEL = 0.0
0224 PHI = 0.0
0225 DO 095 I1= 1,7,1
0226 DO 095 I2= 1,7,1
0227 XVEL = XVEL + (COEKX(I1,I2) *GAMMA**((I2-1))*BETA **((I1-1)
0228 PHI = PHI + (COEKP(I1,I2) *GAMMA**((I2-1))*BETA **((I1-1)
0229 PHI = PHI * 180 / 3.14159
0230 095 WRITE (LI,115) BETA,GAMMA,XVEL,PHI,AR0
0231 IF (LD.NE.0) WRITE (LD,115) BETA,GAMMA,XVEL,PHI,AR0
0232 STOP 7777
0233 END
0234 REAL FUNCTION FNP(NORDER,COEFF,ZX)
0235 REAL COEFF(?)

```

Figure F-2. Listing of Program to Test the Quality of the Calibration: &TEST.
(Continued on next page.)

```

0239      A1 = COEFF(NORDER+1)
0240      IF ( NORDER .EQ. 0 ) GOTO 02
0241      DO 01 I1 = 1,NORDER,1
0242      I = NORDER + 1 - I1
0243      A1 = COEFF(I)+ZX*A1
0244      FND = A1
0245      RETURN
0246      END
0247      REAL FUNCTION FND(NORDER,COEFF,ZX)
0248      REAL COEFF (7)
0249      REAL COEFFD(6)
0250      DO 01 I=1,NORDER,1
0251      COEFFD(I) = COEFF(I+1)*I
0252      A1 = COEFFD(NORDER)
0253      NORDR = NORDER - 1
0254      IF( NORDR .EQ. 0 ) GOTO 03
0255      DO 02 I1 = 1,NORDR,1
0256      I = (NORDR + 1) - I1
0257      A1 = COEFFD(I)+ZX*A1
0258      FND = A1
0259      RETURN
0260      END
0261      REAL FUNCTION SCANR (LU,ICHAN,K)
0262      .....
0263      .....
0264      .....
0265      .....
0266      .....
0267      .....
0268      .....
0269      .....
0270      .....
0271      .....
0272      .....
0273      .....
0274      .....
0275      .....
0276      * Closes scanner and reads DVM, counter.
0277      101 FORMAT (A2)
0278      801 FORMAT ("C")
0279      1001 FORMAT ("I3T3")
0280      1201 FORMAT ("T")
0281      1501 FORMAT ("C")
0282      .....
0283      WRITE ( 8, 801)
0284      WRITE (15,1501)
0285      IC = ICON(ICHAN,0)
0286      WRITE (LU,101) IC
0287      GO TO (01,02) K
0288      .....
0289      01 CALL TRIGR (10)
0290      READ (10, *) DUM
0291      CALL TRIGR (10)
0292      READ (10, *) SCANR
0293      GO TO 03
0294      .....
0295      02 WRITE (12,1201)
0296      READ (12, *) SCANR
0297      .....
0298      03 WRITE (LU, 801)
0299      RETURN
0300      END
0301      INTEGER FUNCTION ICON(I,N)
0302      IC=I+N
0303      IF(IC.LT.10) GO TO 100
0304      CALL CODE
0305      WRITE(ICON,60)IC
0306      60 FORMAT(12)
0307      RETURN
0308      100 ICON=IC+30060H
0309      RETURN
0310      END

```

Figure F-2. Listing of Program to Test the Quality of the Calibration: &T

APPENDIX G

CALIBRATION DATA (C_{PoB}) APPROXIMATION PROGRAM &RES10

As shown in Fig. 19, CPBO is well behaved as a function of pitch angle and Mach number as well. Thus it is approximated as a function of these two variables. Program &RES10 handles this procedure. It is in principal again the same program as &REST8, like &REST9, so that a detailed program description will not be given here. However, it shall be mentioned here that the data which is the basis of the approximation is contained in data file ABNEW2. This is an indication that this file contains all the data necessary to represent the whole calibration.

For the evaluation of the quality of the approximation, errors are printed out as were for &REST8. These are calculated as:

$$\epsilon_{CP_{B0}} = \frac{C_{PB_{0m}} - C_{PB_{0c}}}{C_{PB_{0m}}} \cdot 100$$

index m = known from measurement

index c = calculated

The variation in the order of polynomials for the approximation was changed in two DO-loops also and the one for the best error results chosen. Those coefficients are stored in file MISTCP on cartridge 26. Figure G-1 shows the coefficients

and the associated errors. The highlighted area gives the range of Mach number and pitch angle which will most likely occur. Thus the error distribution within there is most important.

Figure G-2 gives a listing of program &RES10. The similarities to programs &REST8 and &REST9 are obvious, so that no flow chart or further explanations are given.

COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FILE CALSTC2

Morder	Norder	1	2	3	4
1	↓	.504379	2.671250	-9.603358	14.680915
2		-1.369215	1.062072	-2.388952	-12.645025
3		-1.138999	-4.494507	25.229003	-45.602797
4		1.232497	7.475204	-51.004311	53.495722
		1	2	3	4

ERRORS AT EACH POINT

mach	Pitch Angle	1	2	3	4	5	6	7	8	-15°
Number	25°	1	2	3	4	5	6	7	8	
0.2	1	26.031	3.390	-2.575	- .974	.671	1.031	.045	-1.310	.871
	2	-12.993	2.639	-.895	- .023	-.216	.406	.159	-.106	-.235
	3	.104	2.414	1.159	.613	-.636	-1.193	.355	.623	.759
	4	-.219	.255	-.734	-.476	-.264	-.531	.127	-.788	-.049
	5	-.404	.124	-1.169	1.115	.624	.242	-.199	-.966	-.305
0.7	6	1.858	-1.242	-.760	.234	.494	-.012	-.231	-.378	.627
	1	1	2	3	4	5	6	7	8	9

Table G-I. Coefficients and errors for C_{POB} approximation depending on X_{vel} and ϕ .

&RES10 T=00004 IS ON CR00026 USING 00024 BLKS R=0000

```

0001 FTN4.L
0002 PROGRAM RES10 (3,99)
0003 C
0004 C : This is program RES(tore) 10.
0005 C
0006 C : There are some programs REST , which in principle do all the
0007 C : same : They restore calibration data of a probe into a form
0008 C : that can be used to approximate this data by a calibration
0009 C : surface.
0010 C : The software used for the surface approximation is available
0011 C : in the Turbopropulsion Laboratory Binary Library(TPLBL).
0012 C : See NPS67-80-001CR for further reference.
0013 C : In this particular case the calibration data of the
0014 C :
0015 C : NEW A - AND B - PROBES
0016 C :
0017 C : are approximated i
0018 C : CpOB = f(PHI,XVEL)
0019 C
0020 C
0021 C COMMON / MATRIX / A,B
0022 C COMMON / SUMME / PHI,XVEL,CPOB
0023 REAL PLOTR(256),A(49,49),B(49),COEFF(7,7),D(10,54)
0024 INTEGER IDCRC(144),IFILE(3),ISIZE(2),NOCRC(2),ICLR(3)
0025 REAL XVEL(16,16),PHI(16,16),CPOB(16,16),R(16)
0026 DATA PI /3.141593/
0027 DATA IFILE /2HAR,2HNE,2HW2/
0028 DATA NOCR /000033R,040433R/
0029 DATA ICLR /015524H,015515H,006537B/
0030 DATA ISECU /0/
0031 DATA ICR /26/
0032 DATA ITYPE /1/
0033 DATA ISIZE /3,128/
0034 DATA IDCRC /144/
0035 101 FORMAT (" SELECT SET OF COEFFICIENTS FOR BEST RESULTS 1"/" ENTER M
0036 *ORDER AND NORDER NOW :")
0037 149 FORMAT ("((3A2)))
0038 601 FORMAT (///" COEFFICIENTS FOR THE CALIBRATION SURFACE STORED IN FI
0039 *LE : "3A2//)
0040 602 FORMAT ((3X,16(6X,I2)))
0041 603 FORMAT (1X,I2,16(1X,F7.3)/3(3X,16(1X,F7.3)/))
0042 604 FORMAT (///" ERRORS AT EACH POINT (Z)"/)
0043 605 FORMAT ((3X,10(11X,I2)))
0044 606 FORMAT (1X,I2,7(2X,F11.6))
0045 1111 FORMAT (" STATEMENT # "I4 " ERROR # "I4 " ENCOUNTERED 1")
0046 LI = LOGU(1)
0047 C
0048 C :
0049 C : READ DATA FILE ARNEW .
0050 C
0051 C
0052 CALL OPEN (IDCR,IERR,IFILE,IOPIN,ISECU,ICR,IDCRS)
0053 JJ = 1
0054 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0055 CALL READF (IDCR,IERR,D,1080,LEN,1)
0056 JJ = 2
0057 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0058 CALL CLOSE (IDCR,IERR,0)
0059 JJ = 3
0060 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0061 IF
0062 DO 005 I = 1,6,1
0063 DO 005 J = 1,9,1
0064 IJ = IJ + 1
0065 XVEL (I,J) = D(3,IJ)
0066 IF ( J.EQ. 6 ) D(4,IJ) = D(4,IJ) + 0.00001
0067 PHI (I,J) = D(4,IJ) * PI / 180
0068 CPOB (I,J) = D(6,IJ)
0069 NMACH = 0
0070 NPTCH = 0
0071 010 CONTINUE
0072 C
0073 C :
0074 C :
0075 C :
0076 C :
0077 C :
0078 C :
0079 C :
0080 C :
0081 C :
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0083 C :
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0240 C :
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0249 C :
0250 C :
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0255 C :
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0360 C :
0361 C :
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0364 C :
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0401 C :
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1000 C :

```

Figure G-1. Listing of Program to Approximation C_{PoB} Values: &RES10. (Continued on next page.)


```

0079      IJI = 0
0080      DO 060 MU = 1,6,1
0081      DO 060 NU = 1,6,1
0082      MORDER = MU
0083      NORDER = NU
0084      015 CONTINUE
0085      DO 020 I = 1,7,1
0086      DO 020 J = 1,7,1
0087      020 COEFF(I,J) = 0.0
0088      M=MORDER+1
0089      N=NORDER+1
0090      CALL COMAT (A,B,M,N,NMACH,NPITCH)
0091      NEQUS=MAN
0092      CALL ELGJ (NEQUS)
0093      I1=0
0094      DO 025 I = 1,M,1
0095      DO 025 J = 1,N,1
0096      I1 = I1+1
0097      025 COEFF(I,J)= E(I1)
0098      IF ( IJI .NE. 1 ) GOTO 030
0099      IFILE(1) = 2HMI
0100      IFILE(2) = 2HST
0101      IFILE(3) = 2HCP
0102      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
0103      JJ = 4
0104      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0105      CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)
0106      JJ = 5
0107      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0108      CALL WRITF (IDCB,IERR,COEFF,98)
0109      JJ = 6
0110      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0111      CALL CLOSE (IDCB,IERR,0)
0112      JJ = 7
0113      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0114      WRITE (6,601) IFILE
0115      030 CONTINUE
0116      WRITE (6,605) (J,J=1,N,1)
0117      DO 035 I = 1,M,1
0118      035 WRITE (6,606) I,COEFF(I,J),J=1,N,1)
0119      WRITE (6,605) (J,J=1,N,1)
0120
0121
0122
0123 C .....
0124 C : OVERWRITE DATA ARRAY WITH CALCULATED DATA
0125 C : .....
0126 C
0127 C .....
0128 C WRITE (6,604)
0129 C WRITE (6,602) (J,J=1,NPITCH,1)
0130 C DO 050 I = 1,NMACH,1
0131 C DO 045 J = 1,NPITCH,1
0132 C SUM = 0.
0133 C DO 040 I1 = 1,M,1
0134 C DO 040 J1 = 1,N,1
0135 C 040 SUM=SUM+(COEFF(I1,J1)*XVEL(I,J)**(J1-1))*PHI (I,J)**(I1-1)
0136 C 045 R(J)=((CPOR(I,J)-SUM)/CPOR(I,J))*100
0137 C 050 WRITE (6,603) I,(R(J),J=1,NPITCH,1)
0138 C WRITE (6,602) (J,J=1,NPITCH,1)
0139
0140 C IF (IJI .EQ. 1 ) GOTO 065
0141
0142 C 060 CONTINUE
0143 C WRITE (LI,101)
0144 C READ (LI, *) MORDER,NORDER
0145 C IJI = 1
0146 C GOTO 015
0147 C 065 STOP 7777
0148 C END

```

Figure G-1. Listing of Program to Approximation C_{POB} Values: &RES10.

APPENDIX H

TEST DATA ACQUISITION PROGRAM &ABKUL

Program &ABKUL is rather complex. The amount of data gathered and stored is quite extensive. Since the data reduction procedure is faster if only one file contains all data, the use of a single data file seems to be justified.

Before any data acquisition is performed, the file to contain the data is created under a name given by the operator. This way it is ensured that there is sufficient space on the cartridge to store the file. Once this is done, the data array (DATA(20,256)) is preset with zeros and the interface bus and devices are set to remote control. The first part of the data acquisition is for the first on-line calibration. Both Kulite probes are at the same radius as the rotor exit combination probe and all probe yaw angles are fixed to the same angle given by the combination probe. This one is assumed to be the time averaged flow yaw angle. The reference pressure on the back side of the Kulite transducers is changed to a known value and a set of data is recorded. This data includes the pressure readings of the Kulite probes and their reference pressure as well as all the information available from the combination probe. Once this data is collected, the Kulite probe reference pressure is changed to another value and another set of data is acquired. This

procedure is carried out for a total of four different reference pressures, allowing sufficient time after each pressure change for the measuring system to adapt to the new pressure. After the last pressure is applied, the reference pressure is reset to barometric pressure and the data acquisition for the first on-line calibration is completed. During the data acquisition the recorded data is printed out immediately so that its quality can be evaluated right away.

Before the acquisition of high speed data is performed, the operator is asked to specify the number of yaw angles he wants the Kulite probes to be moved to. A maximum of nine is possible and this number should always be favored to ensure sufficient data to cover a range of 160° in yaw angle as explained in 6.3. The program asks the operator to set both Kulite probes to the first yaw angle and to initiate the data acquisition. In a first DO-loop data from the type A probe is gathered for 256 consecutive circumferential positions. Each of the 256 values is the average of 40 single samples which are acquired on consecutive revolutions. In a second DO-loop the same kind of data is acquired from the B probe. Since the two probes are mounted on the compressor case wall separated by 270° circumferentially, the trigger numbers where the data acquisition starts are separated by a number of $1728 \text{ cts.} = 270^{\circ}$ for the two probes. (The trigger device splits 360° up into 2304 single counts. Both probes acquire data for 256 counts, 40° respectively. Since the rotor has 18 blades, two blade passages are covered.)

When the second DO-loop is done, steady state data from the combination probe and the Kulite probes is acquired. This data is of the same kind as that for the on-line calibration data and is in general very helpful for checking purposes. It is printed out as soon as it is acquired. From the high speed data the overall average values for all 256 positions from A and B probes are derived and printed out also.

The DO-loop is continued by the operator initializing the acquisition for another yaw angle setting of both probes.

When the data for all desired yaw positions is acquired, a second on-line calibration is performed. The results are printed out immediately so that they can be compared to those from the first calibration and obvious errors can be detected right away. From the two on-line calibrations slopes and intercepts are derived for both probes as described in 6.3.

Finally the data is stored in the assigned file.

Figure H-1 gives a flow chart of program &ABKUL, while Fig. H-2 is a listing.

<u>Variables</u>	<u>Type</u>	<u>Description</u>
AVRGA	Real	Average value of A probe output
AVRGB	Real	Average value of B probe output
BUFR(1664)	Integer	Buffer array
DATA(20,256)	Real	Data array
DCA	Real	DC-level reading of A probe
DCB	Real	DC-level reading of B probe

<u>Variables</u>	<u>Type</u>	<u>Description</u>
DE	Real	Voltage difference between combination probe and reference temperature probe thermocouple
E	Real	Voltage reading of combination probe thermocouple
FSVLTG	Real	Calibration factor Kulite probe reading
IBUFF(99)	Integer	Array for Kulite sample values
IBLADE	Integer	Number of compressor rotor blade pairs to be investigated
ICLR(3)	Integer	Command to clear line above the cursor
ICOUNT	Integer	Number of acquired data points (1 through 256)
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IDCBS	Integer	Data control block length
IDUM	Integer	Dummy variable
IFILE(3)	Integer	Array containing file name
IL	Integer	Total number of words stored in data file (two words for one value)
ISECU	Integer	Security code
IRPM	Integer	Rotational speed derived from triggered measurements
ISIZE(2)	Integer	Array to specify fill dimensions
ITYPE	Integer	Type of data file
LI	Integer	Input device number
LO	Integer	Output device number
MASK	Integer	Masking variable
NOLF	Integer	No line feed command

<u>Variables</u>	<u>Type</u>	<u>Description</u>
PBARO	Real	Barometric pressure
PCAL	Real	Calibration pressure for the Scanivalve
PREF	Real	Reference pressure for the Kulite probes
P1, P23, P4	Real	Pressure readings for the combination probe
RPM	Real	Compressor speed as read from counter
SECON	Real	Intercept of either A or B probe calibration
SLOPE	Real	Slope of either A or B probe calibration
TARE	Real	"Zero drift" for Scanivalve transducer
X(4)	Real	Array for on-line calibration data
XIMA	Real	Immersion of A probe
XIMB	Real	Immersion of B probe
XIMC	Real	Immersion of combination probe
Y(4)	Real	Array for on-line calibration data
YAWA	Real	Yaw angle of A probe
YAWB	Real	Yaw angle of B probe
YAWC	Real	Yaw angle of C probe
YAWP	Real	Total number of yaw positions for the A and B probe

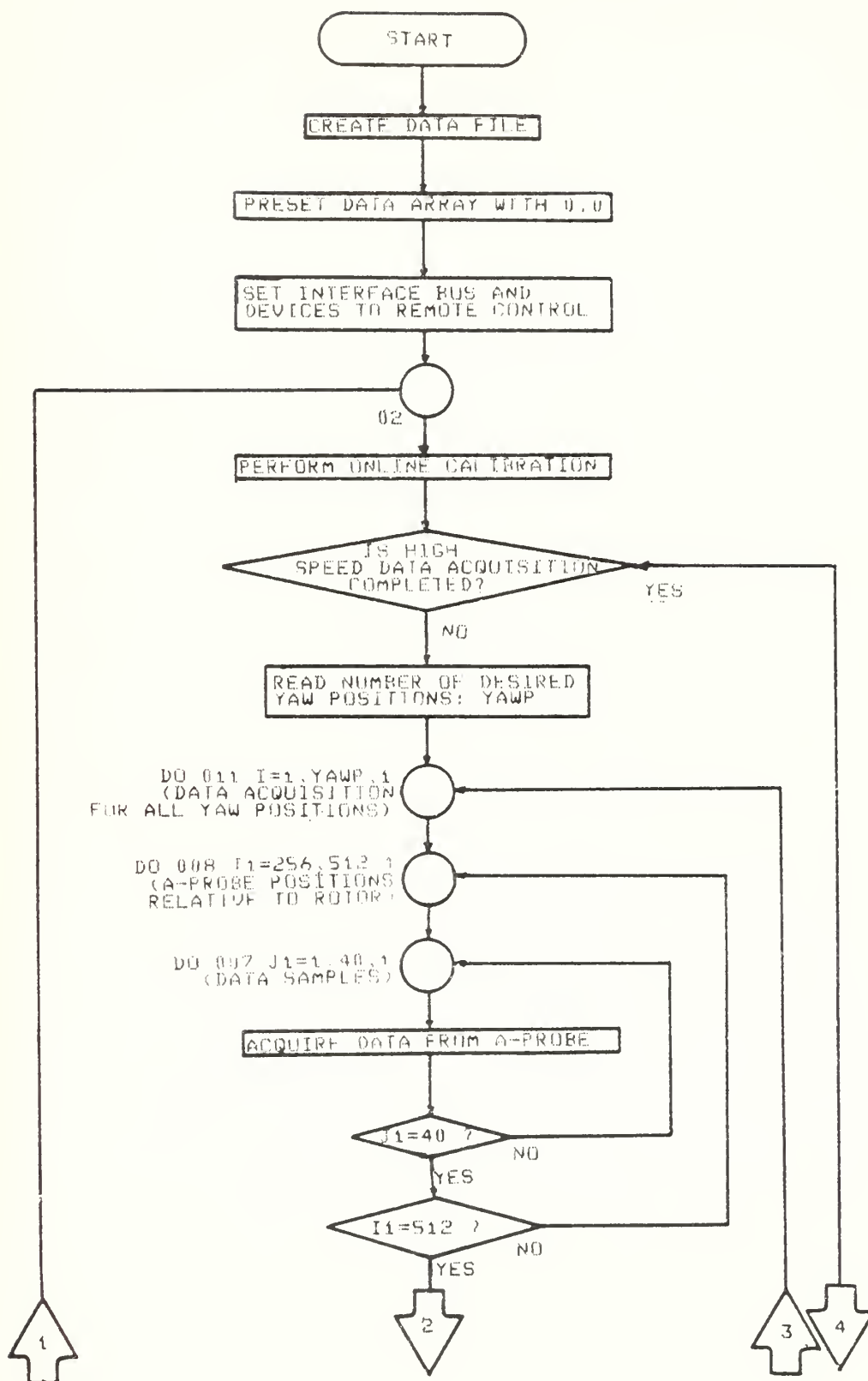


Figure H-1. Flow Chart of Data Acquisition Program &ABKUL.
(Continued on next page.)

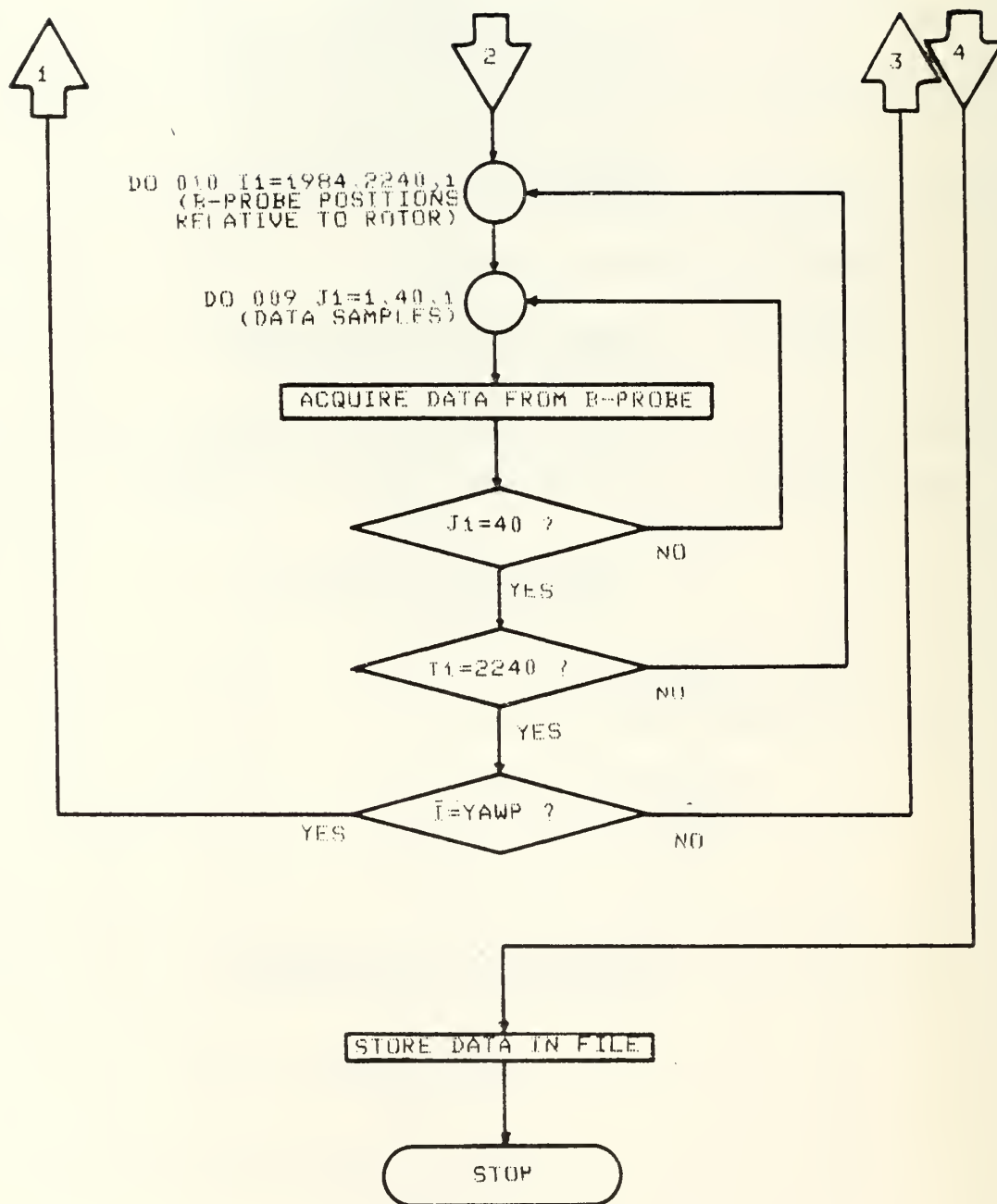


Figure H-1. Flow Chart of Data Acquisition Program &ABKUL.
(Continued on next page.)

ABKUL T=00004 IS ON CR00026 USING 00061 BLKS R=0000

```

0001 FTN4,L
0002 PROGRAM ABKUL (3,99)
0003
0004
0005 . This is program ABKUL(ite).
0006 . It performs an online calibration of the A and B kuliteprobes
0007 . and a data acquisition for 7 yaw positions of these probes as
0008 . well.
0009
0010 . Author : Friedrich Neuhoﬀ
0011 . Date : July 28, 1981
0012
0013
0014 *****
0015 *
0016 * NOTE : IF THE "C" WILL BE REMOVED FROM THE STATEMENTS
0017 * CONTAINING ASTERISKS IN COLUMN 73 AND HIGHER
0018 * NO STEADY STATE DATA WILL BE ACQUIRED AND ONLY
0019 * ONE SET OF HIGH SPEED DATA WILL BE TAKEN
0020 *
0021 *****
0022
0023 DIMENSION IBUFF(99),ICGR(192)
0024 REAL DATA(20,256),X(4),Y(4),AVRGA,AVRGB
0025 INTEGER BUFR (1664)
0026 INTEGER NDLF,IDCB(144),ICLR(3),IFILE(3),ISIZE(2)
0027 DATA IDCB / 144/
0028 DATA IFCU / 00/
0029 DATA ICR / 28/
0030 DATA ITYPE / 1/
0031 DATA IL / 10240/
0032 DATA ICIZE(1) / 80/
0033 DATA ISIZE(2) / 128/
0034 DATA NDLF / 0065378/
0035 DATA ICLR / 0155248,0155158,0065378/
0036 DATA MASK / 1777008/
0037 DATA FSVLTG / .1E01/
0038
0039 101 FORMAT (' This is program ABKUL(ite).'" It first performs a data
0040 * acquisition for an online calibration of the A and B " probes."/
0041 * Then it takes paced data from the probes at 7 different yaw posi
0042 * tions " interactively with the operator. At the end another set
0043 * of data for an online" calibration is acquired'" The whole r
0044 * aw data is stored in one file!")
0045
0046 102 FORMAT (//// "The online calibration shall be performed now!"/" It
0047 * allows four different reference pressures!/" When the first ref
0048 * pressure is applied correctly, key GO")
0049
0050 103 FORMAT(///36X "Online calibration"///)
0051 104 * Inner A pr. yaw A pr. yaw comb. "10X"P1"9X"P23"10X"P4"/5X"Point
0052 * Inner B pr. yaw B pr. yaw comb. "10X"DCA"8X"Pref"10X"Tr"/13X"Inner B pr.
0053 * yaw B pr. "9X"DCA"9X"RPM"9X"Dt"///)
0054
0055 105 FORMAT (/12X,5(2X,F10.6)/5X,12,5X,5(2X,F10.6)/12X,5(2X,F10.6))
0056 106 FORMAT (" Apply the next ref. press. and key GO when the condition
0057 * is stable"/"enough for the next reading!")
0058
0059 107 FORMAT(" 1st online calibration done!"/" Reset the ref. press. for
0060 * the high speed data acquisition!"/" Enter the number of different
0061 * yaw angles you want."/ " Hit CR after that to continue!")
0062
0063 108 FORMAT(///36X "Average values from paced run"///)
0064 109 FORMAT (" Adjust both kulite probes to yaw angle number:"I2/" Key
0065 * GO when this is done!")
0066
0067 110 FORMAT(/24X"A probe"30X"B probe"/26X"Glope"6X"Intercept * "10X"Slo
0068 * pe"6X"Intercept"/47X"*/" 1st calibration"2(3X,F12.6)" * "2(3X,F12
0069 * .6)/47X"*/" 2nd calibration"2(3X,F12.6)" * "2(3X,F12.6))
0070
0071 111 FORMAT (" Second online calibration done!"/" Reset the ref. press.
0072 * and consider the data acquisition to be completed!/" Compare th
0073 * e results of the two online calibrations and check for drift!/" I
0074 * f the drift can be accepted, key in the file name you want the dat
0075 * a to be stored in!")
0076
0077 112 FORMAT (" Averaged values paced output : A probe : "F10.5" B probe
0078 * : "F10.5")
0079
0080 148 FORMAT (" Output input data to any other device? Enter NO
0081 * or LU# 1"/" "A2")
0082
0083 149 FORMAT (3A2)
0084
0085 150 FORMAT (I2)
0086
0087 151 FORMAT ("CA")
0088
0089 1001 FORMAT ("F1R7M3A1H0T3")
0090
0091 1201 FORMAT ("PF4GBT")
0092
0093 1501 FORMAT ("CA")
0094
0095
0096 1111 FORMAT (' STATEMENT * "IF" ERROR * "I" ENCOUNTERED!')

```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```

0079      LI = LOGLU(ISESSN)
0080 77 WRITE (LI, 148) NOLF
0081      READ (LI, 149) IDUM
0082      WRITE (LI, 149) (ICLR, I1=1,2)
0083      IF ( IDUM .EQ. 2HNO ) GO TO 78
0084      CALL CODE
0085      READ (IDUM, 150) LO
0086      IF ( LO .EQ. 1 ) GO TO 79
0087      IF ( LO .EQ. 6 ) GO TO 79
0088      IF ( LO .EQ. 18 ) GO TO 79
0089      GO TO 77
0090 78 LO = 0
0091 79 IF ( LO .EQ. LI ) LO = 0
0092      WRITE (LI, 101)
0093
0094 C .....
0095 C Preset data array with zeros!
0096 C .....
0097 C .....
0098 C .....
0099 DO 01 I = 1, 20, 1
0100 DO 01 J = 1, 256, 1
0101 01 DATA (I, J) = 0.0
0102 C .....
0103 C .....
0104 C Set interface bus and devices to remote control !
0105 C .....
0106 C .....
0107 CALL ABRT(7, 2)
0108 CALL RMOTE( 8 )
0109 CALL RMOTE(10)
0110 CALL RMOTE(12)
0111 CALL RMOTE(15)
0112 WRITE ( 8, 801)
0113 WRITE (10, 1001)
0114 WRITE (12, 1201)
0115 WRITE (15, 1501)
0116 C .....
0117 C .....
0118 C Perform the data acquisition for the first online calibration .
0119 C .....
0120 C .....
0121 J = 1
0122 C GOTO 05
0123 C .....
0124 02 I = 1
0125 WRITE (LI, 103)
0126 READ (LI, 149) IDUM
0127 IF ( IDUM .NE. 2HGO ) GOTO 02
0128 WRITE (LI, 103)
0129 IF ( LO .NE. 0 ) WRITE (LO, 103)
0130 WRITE (LI, 104)
0131 IF ( LO .NE. 0 ) WRITE (LO, 104)
0132 03 TARE2 = ACQN ( 4, 1, 10)
0133 PCAL = ACQN ( 4, 2, 10)
0134 P1 = ACQN ( 4, 6, 10)
0135 P23 = ACQN ( 4, 7, 10)
0136 P4 = ACQN ( 4, 8, 10)
0137 RPM = SCANR( 8, 17, 2)
0138 PHARO = SCANR( 8, 25, 1)
0139 XIMC = SCANR( 8, 32, 1)
0140 YAWC = SCANR( 8, 33, 1)
0141 XIMA = SCANR( 8, 34, 1)
0142 YAWA = SCANR( 8, 35, 1)
0143 XIMB = SCANR( 8, 36, 1)
0144 YAWB = SCANR( 8, 37, 1)
0145 PREF = SCANR( 8, 39, 1)
0146 E = SCANR(15, 18, 1)
0147 DE = SCANR(15, 19, 1)
0148 DCA = SCANR(15, 22, 1)
0149 DCB = SCANR(15, 23, 1)
0150 DATA(1, J+ 1) = PCAL
0151 DATA(1, J+ 2) = P1
0152 DATA(1, J+ 3) = P23
0153 DATA(1, J+ 4) = P4
0154 DATA(1, J+ 5) = RPM
0155 DATA(1, J+ 6) = PHARO
0156 DATA(1, J+ 7) = XIMC
0157 DATA(1, J+ 8) = YAWC
0158 DATA(1, J+ 9) = XIMA

```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```

0159 DATA(1,J+10) = YAWA
0160 DATA(1,J+11) = XIMB
0161 DATA(1,J+12) = YAWB
0162 DATA(1,J+13) = PREF
0163 DATA(1,J+14) = E
0164 DATA(1,J+15) = DE
0165 DATA(1,J+16) = DCA
0166 DATA(1,J+17) = DCB
0167 WRITE (LI,105) XIMC,YAWC,P1,P23,P4,I,XIMA,YAWA,DCA,PREF,E,XIMB,
0168 *YAWB,DCB,RPM,DE
0169 IF (LO.NE.0) WRITE (LO,105) XIMC,YAWC,P1,P23,P4,I,XIMA,YAWA,DC
0170 *A,PREF,E,XIMB,YAWB,DCB,RPM,DE
0171 IF (J.EQ.61) GOTO 05
0172 IF (J.EQ.141) GOTO 10
0173 04 WRITE (LI,106)
0174 READ (LI,149) IDUM
0175 WRITE (LI,149) (ICLR,I1=1,3)
0176 IF (IDUM.NE.2HGO) GOTO 04
0177 J = J + 20
0178 I = I + 1
0179 GOTO 03
0180 05 WRITE (LI,107)
0181 READ (LI,*) YAWP
0182 YAWP = YAWP * 2
0183 .....
0184 .....
0185 .....
0186 .....
0187 .....
0188 .....
0189 C WRITE (LI,108)
0190 IF (LO.NE.0) WRITE (LO,108)
0191 WRITE (LI,104)
0192 IF (LO.NE.0) WRITE (LO,104)
0193 DO 09 J1 = 2,YAWP,2
0194 JJ = J1 / 2
0195 06 WRITE (LI,109) JJ
0196 C READ (LI,149) IDUM
0197 WRITE (LI,149) (ICLR,I1=1,3)
0198 IF (IDUM.NE.2HGO) GOTO 06
0199 AVRGA = 0.0
0200 ICOUNT = 0
0201 START = 256
0202 STOP = 256 + 256
0203 DO 61 I1 = START,STOP,1
0204 ICOUNT = ICOUNT + 1
0205 IBLADE = I1 + 100000H
0206 CALL EXEC (3,19)
0207 CALL EXEC (1,19,IRPM,1,IBLADE)
0208 CALL EXEC (1,20,IBUFF,30,0,0)
0209 RBUFF = 0.0
0210 DO 62 J1 = 1,30,1
0211 IBUFF(J1) = IAND(IBUFF(J1),MASK)
0212 RBUFF = FLOAT ( IBUFF(J1) ) / 32768. + RBUFF
0213 62 DATA(J1,ICOUNT) = ((RBUFF*FSULIG)/30)
0214 AVRGA = AVRGA + DATA (J1,ICOUNT)
0215 61 CONTINUE
0216 AVRGA = AVRGA / 256
0217 C DO 5454 I = 1,32,1
0218 CS454 WRITE (6,1313) (J,DATA(JI,J)), J = 1,256,32 )
0219 C1313 FORMAT (0(' DATA("13")="F6.0)')
0220 WRITE (1,222) AVRGA
0221 222 FORMAT(' AVRGA = "F12.6)
0222 AVRGA = 0.0
0223 ICOUNT = 0
0224 START = 1696
0225 STOP = 1696 + 256
0226 DO 64 I1 = START,STOP,1
0227 ICOUNT = ICOUNT + 1
0228 IBLADE = I1 + 100000H
0229 CALL EXEC (3,19)
0230 CALL EXEC (1,19,IRPM,1,IBLADE)
0231 CALL EXEC (1,20,IBUFF,30,1,0)
0232 RBUFF = 0.0
0233 DO 63 J1 = 1,30,1
0234 IBUFF(J1) = IAND(IBUFF(J1),MASK)
0235 RBUFF = FLOAT ( IBUFF(J1) ) / 32768. + RBUFF
0236 63 DATA(JI+1,ICOUNT) = ((RBUFF*FSULIG)/30)
0237 AVRGA = AVRGA + DATA (JI+1,ICOUNT)
0238 64 CONTINUE

```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)

```

0239      AVRGB = AVRGB / 256
0240      DO 5455 I = 1, 32, 1
0241 C5455 WRITE (6,1313) (J, DATA(JI+1,J), J = I, 256, 32)
0242      WRITE (1,333) AVRGB
0243      333 FORMAT(4 AVRGB = "F12.6)
0244
0245 C
0246      : Get necessary steady state data !
0247 C
0248      :
0249 C
0250      GOTO 099
0251      I = (JJ - 1) * 20 + 1
0252      DATA(20,I) = ACQN ( 4, 1, 10)
0253      DATA(20,I+1) = ACQN ( 4, 2, 10)
0254      DATA(20,I+2) = ACQN ( 4, 5, 10)
0255      DATA(20,I+3) = ACQN ( 4, 7, 10)
0256      DATA(20,I+4) = ACQN ( 4, 11, 10)
0257      DATA(20,I+5) = SCANR(8,25,1)
0258      DATA(20,I+6) = SCANR(8,32,1)
0259      DATA(20,I+7) = SCANR(8,33,1)
0260      DATA(20,I+8) = SCANR(8,34,1)
0261      DATA(20,I+9) = SCANR(8,35,1)
0262      DATA(20,I+10) = SCANR(8,36,1)
0263      DATA(20,I+11) = SCANR(8,37,1)
0264      DATA(20,I+12) = SCANR(8,39,1)
0265      DATA(20,I+14) = SCANR(15,18,1)
0266      DATA(20,I+15) = SCANR(15,19,1)
0267      DATA(20,I+16) = SCANR(15,52,1)
0268      DATA(20,I+17) = SCANR(15,53,1)
0269      DATA(20,I+18) = AVRG
0270      DATA(20,I+19) = AVRGB
0271      WRITE (LI,105) DATA(20,I+7), DATA(20,I+8), DATA(20,I+2), DATA(20,I+3)
0272      * DATA(20,I+4), JJ, DATA(20,I+9), DATA(20,I+10), DATA(20,I+16),
0273      * DATA(20,I+13), DATA(20,I+14), DATA(20,I+11), DATA(20,I+12),
0274      * DATA(20,I+17), DATA(20,I+5), DATA(20,I+15)
0275      WRITE (LI,112) AVRG, AVRGB
0276      IF (LO.NE.0) WRITE (LO,105) DATA(20,I+7), DATA(20,I+8), DATA(20,I+2),
0277      * DATA(20,I+4), JJ, DATA(20,I+9), DATA(20,I+10), DATA
0278      * (20,I+16), DATA(20,I+13), DATA(20,I+14), DATA(20,I+11), DATA(20,I+12),
0279      * DATA(20,I+17), DATA(20,I+5), DATA(20,I+15)
0280      IF (LO.NE.0) WRITE (LO,112) AVRG, AVRGB
0281 C
0282      :
0283 C
0284      : Next yaw position.
0285 C
0286      09 CONTINUE
0287      J = 81
0288      GOTO 02
0289      10 CONTINUE
0290 C
0291      :
0292 C
0293      : Release interface bus and devices from remote control
0294 C
0295      CALL CLEAR (7,1)
0296      CALL LOCL (7)
0297
0298      DO 11 I = 1, 4, 1
0299      J = (I-1) * 20 + 17
0300      X(I) = DATA(1, J)
0301      JJ = J - 3
0302      Y(I) = DATA(1, JJ)
0303      11 CALL CURVE (4, X, Y, SLOPE, SECON)
0304      DATA(1,160) = SLOPE
0305      DATA(1,161) = SECON
0306      DO 12 I = 1, 4, 1
0307      J = (I-1) * 20 + 18
0308      X(I) = DATA(1, J)
0309      JJ = J - 4
0310      Y(I) = DATA(1, JJ)
0311      12 CALL CURVE (4, X, Y, SLOPE, SECON)
0312      DATA(1,170) = SLOPE
0313      DATA(1,171) = SECON
0314      DO 13 I = 1, 4, 1
0315      J = (I-1) * 20 + 97
0316      X(I) = DATA(1, J)
0317      JJ = J - 3
0318      Y(I) = DATA(1, JJ)
0319      13

```

Figure H-2. Listing of Data Acquisition Program &ABKUL.
(Continued on next page.)


```

0319 CALL CURVE (4,X,Y,SLOPE,SECON)
0320 DATA(1,180) = SLOPE
0321 DATA(1,181) = SECON
0322 DO 14 I = 1,4,1
0323 J = (I-1) * 20 + 98
0324 X(I) = DATA(1,J)
0325 JJ = J - 4
0326 14 Y(I) = DATA(1,JJ)
0327 CALL CURVE (4,X,Y,SLOPE,SECON)
0328 DATA(1,190) = SLOPE
0329 DATA(1,191) = SECON
0330 WRITE (LI,110) ( DATA(1,I), DATA(1,I+1), I = 160,190,10)
0331 IF(LO.NE.0) WRITE(LO,110) ( DATA(1,I), DATA(1,I+1), I = 160,190,10)
0332 WRITE (LI,111)
0333 READ (LI,149) IFILE
0334 CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCRS)
0335 II = 1
0336 IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
0337 CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCRS)
0338 II = 2
0339 IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
0340 CALL WRITE (IDCB,IERR,DATA,IL)
0341 II = 3
0342 IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
0343 CALL CLOSE (IDCB,IERR,0)
0344 II = 4
0345 IF ( IERR .LT. 0 ) WRITE (1,1111) II,IERR
0346 STOP 7777
0347 END

```

Figure H-2. Listing of Data Acquisition Program &ABKUL.

APPENDIX I

PROCESSING PROGRAMS &SPLIT AND &WAVE FOR TEST DATA

As stated in 6.3 a plot of the acquired high speed data is very desirable since it represents the fastest way to judge the quality of the data. As the graphics software requires much storage space within a program, it is not possible to read the complete data file into a plot program. A utility program--&SPLIT--has been created which splits the data array into two smaller arrays containing either A or B probe data. These arrays contain the data for the on-line calibration and steady state also. They are both stored under different names, which are operator input.

Since program &SPLIT is a very short and simple program, only a listing is given in Fig. I-1. Explanations are given as needed within the listing. The two newly created files are stored on the same cartridge as the original raw data file.

Program &WAVE provides means to read the smaller data files and to plot their contents. If the variable POS is assigned to be the circumferential position of the probe readings where the starting position is set to 1 and the end position to 256, the pressure distribution can be expressed as a function $P = P(\text{pos})$ for all nine yaw angles. These functions can be plotted by program &WAVE. The plot is a straight line connection of all points.

As mentioned in 6.3 program &WAVE serves two purposes: plotting Kulite data from an existing file and acquiring data from any of the 16 A/D channels and plotting it right away. The decision as to which of the two options shall be used has to be made first by the operator. If it is desired to plot data from a data file, the operator has to key in the file name and the cartridge reference number. This file is then read into a data array. For each probe yaw angle setting there is one pressure distribution $P = P(POS)$ and the operator is asked to specify the one he wants to plot. The choice of plotting on the CRT screen or the X-Y plotter has to be made as well as whether a whole new frame for the plot is needed. Without further input the graph is developed. Other data from the same file can be plotted without rerunning the program or it can be stopped at this point.

If the second feature of the program should be exercised, it has to be specified at the very beginning, when asked for this decision. An A/D channel number has to be entered which corresponds to the Kulite transducer that shall be observed. The number of samples to be taken at each of the 256 positions also has to be put in. This initializes the data acquisition process. Once all the data is acquired, the operator has to decide whether he needs a new frame or not and where he would like to have his plot (CRT or X-Y plotter). As soon as the plot is dumped, the program can either be stopped or started from the very beginning.

Figure I-2 shows a flow chart of program &WAVE, while Fig. I-3 is a listing.

<u>Variable</u>	<u>Type</u>	<u>Description</u>
AD	Integer	Dummy Variable
CHANL	Integer	A/D channel number
DATA(11,256)	Real	Data Array
FSVLTG	Real	Calibration factor for Kulite probe reading
IBUFF(99)	Integer	Array for Kulite sample values
IBUM	Integer	Dummy variable
ICR	Integer	Cartridge reference number
ID	Integer	
IDCB(144)	Integer	Data control block
IDCBS	Integer	Data control block length
IDUM	Integer	Dummy variable
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphics control block
IL	Integer	Total number of words stored in data file (two words for one value)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
LI	Integer	Input device number
LU	Integer	Output device (screen/plotter) number
MASK	Integer	Masking variable
N	Integer	Number of samples to be averaged

<u>Variable</u>	<u>Type</u>	<u>Description</u>
RBUFF	Real	Real value of single sample
RBUFO	Real	Sum of all real value samples for one position
X(256)	Real	Real data array
Y(256)	Real	Real data array

&SPLIT T=00004 IS ON CR00026 USING 00021 RLKS R=0000

```

0001 FTN4,L
0002 PROGRAM SPLIT(3,99)
0003 C
0004 C
0005 C .....
0006 C This program splits the large data file as created by program.
0007 C ARKUL into two separate data files.
0008 C One contains the waveforms of the A-probe and the other the
0009 C one from the B-probe!
0010 C
0011 C
0012 REAL DATA(20,256),DATAS(11,256)
0013 INTEGER IDCBS(144),IFILE(3),ISIZE(2)
0014 DATA IDCBS / 144/
0015 DATA ISECU / 00/
0016 DATA ITYPE / 1/
0017 DATA ISIZE(2) / 128/
0018 101 FORMAT(" ENTER THE NAME OF THE RAW DATA FILE : ")
0019 102 FORMAT(" ENTER THE CARTRIDGE REFERENCE NUMBER: ")
0020 103 FORMAT(" ENTER THE NAME FOR THE FILE CONTAINING A-PROBE DATA")
0021 104 FORMAT(" ENTER THE NAME FOR THE FILE CONTAINING B-PROBE DATA")
0022 149 FORMAT((3A2))
0023 1111 FORMAT(" STATEMENT # : "I2" ERROR # : "I4" DISCOVERED!")
0024 ISIZE(1) = 80
0025 IL = 10240
0026 C
0027 C .....
0028 C READ RAW DATA FILE INTO ARRAY DATA(20,256)
0029 C
0030 WRITE (1,101)
0031 READ (1,149) IFILE
0032 WRITE (1,102)
0033 READ (1,*) ICR
0034 CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)
0035 JJ = 1
0036 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0037 CALL READF (IDCB,IERR,DATA,IL,LEN,1)
0038 JJ = 2
0039 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0040 CALL CLOSE (IDCB,IERR,0)
0041 JJ = 3
0042 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0043 C
0044 C .....
0045 C READ A-PROBE DATA INTO SEPARATE ARRAY
0046 C
0047 C
0048 C
0049 DO 05 J = 1,9,1
0050 DU 05 I = 1,256,1
0051 J1 = J * 4
0052 J2 = J + 1
0053 DATAS(J2,I) = DATA(J1,I)
0054 DATAS(1,I) = DATA(1,I)
0055 05 DATAS(1,I) = DATA(20,I)
0056 ISIZE(1) = 44
0057 IL = 5632
0058 C
0059 C .....
0060 C READ FILENAME FOR A-PROBE DATA AND STORE A-PROBE DATA.
0061 C
0062 C
0063 C
0064 WRITE (1,103)
0065 READ (1,149) IFILE
0066 CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
0067 JJ = 4
0068 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0069 CALL OPEN (IDCB,IERR,IFILE,IOPIN,ISECU,ICR,IDCBS)
0070 JJ = 5
0071 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0072 CALL WRITE (IDCB,IERR,DATAS,IL)
0073 JJ = 6
0074 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0075 CALL CLOSE (IDCB,IERR,0)
0076 JJ = 7
0077 IF (IERR.LT.0) WRITE (1,1111) JJ,IERR
0078 C

```

Figure I-1. Listing Program to Split Up Big Raw Data Array From A-B Probe Into Smaller Arrays: &SPLIT.
(Continued on next page.)


```

0079 C      :      READ B-PROBE DATA INTO SEPARATE ARRAY .      :
0080 C      :      :      :      :      :      :      :      :      :
0081 C      :      :      :      :      :      :      :      :      :
0082 C      :      :      :      :      :      :      :      :      :
0083 DO 07      J = 1, 9, 1      :
0084 DO 07      I = 1, 256, 1      :
0085      J1 = ( J + 2 ) + 1      :
0086      J2 = J + 1      :
0087      DATAS(J2,I) = DATA(J1,I)      :
0088      DATAS(1,I) = DATA(1,I)      :
0089      DATAS(11,I) = DATA(20,I)      :
0090 C      :      :      :      :      :      :      :      :      :
0091 C      :      :      :      :      :      :      :      :      :
0092 C      :      :      :      :      :      :      :      :      :
0093 C      :      :      :      :      :      :      :      :      :
0094 C      :      :      :      :      :      :      :      :      :
0095      WRITE (1,104)      :
0096      READ (1,149) IFILE      :
0097      CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)      :
0098      JJ = 7      :
0099      IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR      :
0100      CALL OPEN (IDCB,IERR,IFILE,IOPFN,ISECU,ICR,IDCBS)      :
0101      JJ = 8      :
0102      IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR      :
0103      CALL WRITEF (IDCB,IERR,DATAS,IL)      :
0104      JJ = 9      :
0105      IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR      :
0106      CALL CLOSE (IDCB,IERR,0)      :
0107      JJ = 10      :
0108      IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR      :
0109      STOP 7777      :
0110      END      :

```

Figure I-1. Listing of Program to Split Up Big Raw Data Array From A-B Probe Into Two Smaller Arrays: &SPLIT.

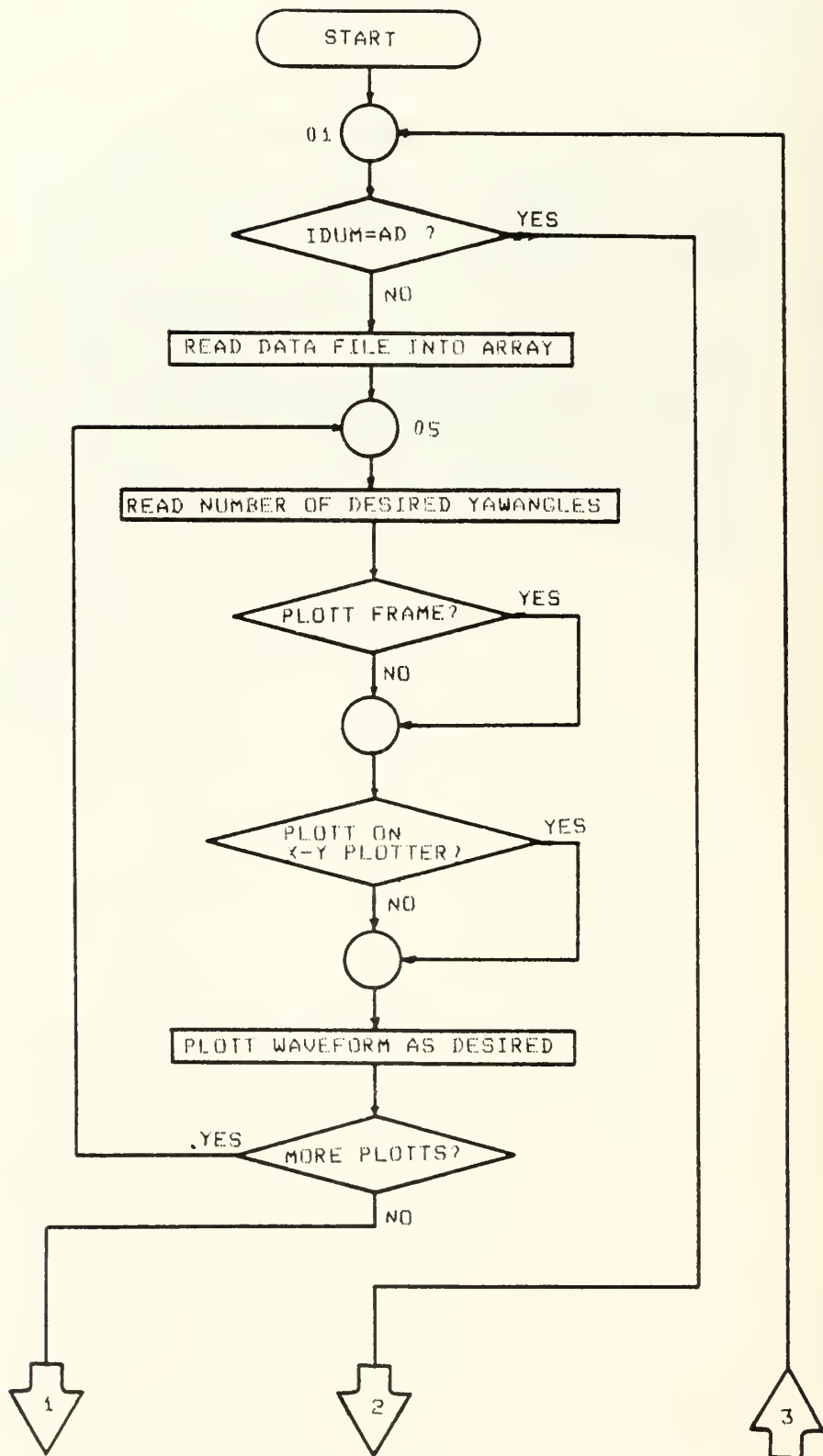


Figure I-2. Flow Chart of Data Acquisition and Plotter Program &WA

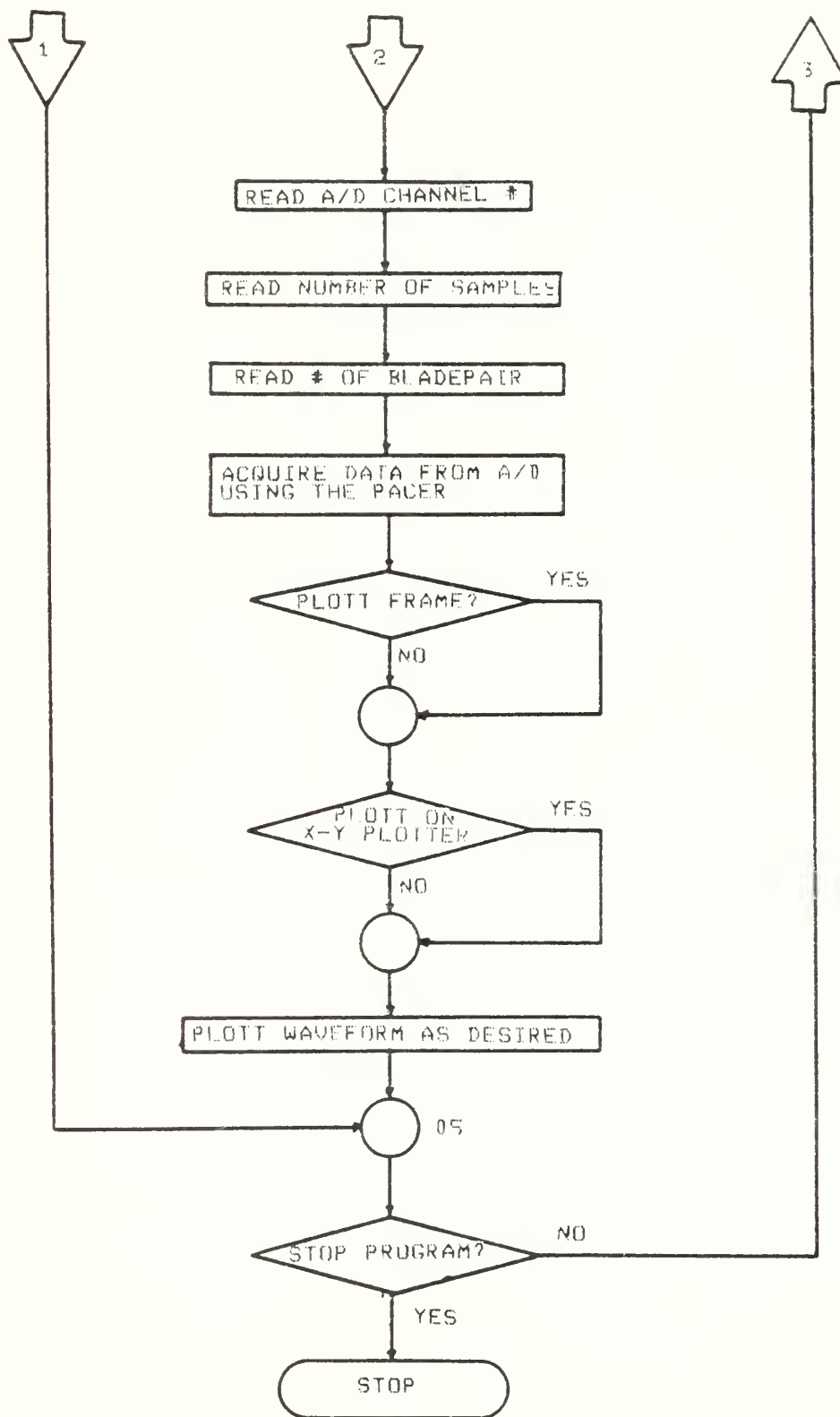


Figure I-2. Flow Chart of Data Acquisition and Plotter Program &WAVE.

WAVE T=00004 IS ON CR00027 USING 00022 BLKS R=0000

```

0001 FTN4,L
0002 PROGRAM WAVE (3,99)
0003 .....
0004 .....
0005 .. This is program WAVE
0006 .. It plotts waveforms as read from either :
0007 .. a data file created using test data from the TX-compressor
0008 .. or from a specified AD channel right away.
0009 .....
0010 .....
0011 DIMENSION IGCR(192),IBUFF(99)
0012 REAL DATA(11,256),X(256),Y(256)
0013 INTEGER IDCR(144),IFILE(3),ISIZE(2),N,CHANL
0014 DATA IDCRS / 144/
0015 DATA ISECU / 00/
0016 DATA ITYPE / 1/
0017 DATA IL / 5632/
0018 DATA ISIZE(1) / 44/
0019 DATA ISIZE(2) / 128/
0020 DATA MASK / 177700B/
0021 DATA FSULTG / .1E01/
0022 .....
0023 100 FORMAT (" This is program WAVE. "/" It can plott a waveform as read
0024 * form the A/d or from a data file. "/" Decide now, which of the two
0025 * options you want! "/" Key AD if you want to take a new reading. An
0026 * ythingelse "/" will ask for further informations for a data file.")
0027 101 FORMAT ("Enter the name of the data file!")
0028 102 FORMAT ("Enter the Cartridge ref. number!")
0029 103 FORMAT(" Do you want another waveform to be plottet?/" Enter yes,
0030 * if so, anything else if not!")
0031 104 FORMAT(" Do you want to stop this program or plot some more waves?
0032 * "/" If you are going to stop it, just key STOP. Anything else will
0033 * give you further instructions!")
0034 105 FORMAT (/12X,5(2X,F10.6)/5X I2,5X,5(2X,F10.6)/12X,5(2X,F10.6))
0035 107 FORMAT(" Do you need a complete new frame?/" Answer YES or NO!")
0036 108 FORMAT(" If you want the plott on the plotter, key PL, anythingels
0037 *e for the terminal !")
0038 113 FORMAT(" You decided to to get a waveform from the AD!/"Enter the
0039 * following now : AD channel")
0040 114 FORMAT(" Number of repetitions, blndepair (1-9) :")
0041 115 FORMAT(" Enter the corresponding number for the waveform you want
0042 *to draw!/" The arrangement is:"/" Yaw pos # 1
0043 * 2 3 9"/9X" DATA( 1,J), DATA(2,J), DATA(3,J), ...
0044 *... DATA( 9,J) - Probe"/)
0045 116 FORMAT(" Do you want a plot of another waveform?/" If so, key YE.
0046 *Any other key will stop the program!")
0047 149 FORMAT ((3A2))
0048 1111 FORMAT (" STATEMENT # : "I3" ERROR # : "I4" DETECTED")
0049 LI = LOGU(ISESSN)
0050 001 WRITE (LI,100)
0051 READ (LI,149) IDUM
0052 IF ( IDUM .EQ. 2HAD ) GOTO 025
0053 WRITE (LI,101)
0054 READ (LI,149) IFILE
0055 WRITE (LI,102)
0056 READ (LI,*) ICR
0057 CALL OPEN ( IDCR,IERR,IFILE,IOPIN,ISECU,ICR,IDCRS)
0058 JJ = 1
0059 IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0060 CALL READF (IDCR,IERR,DATA,IL,LEN,1)
0061 JJ = 2
0062 IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0063 JJ = 3
0064 CALL CLOSE (IDCR,IERR,0)
0065 IF (IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0066 005 WRITE (LI,115)
0067 READ (LI,*) I
0068 I1 = I + 1
0069 XK = 1.0
0070 DO 010 J = 1,256,1
0071 X(J) = J * XK
0072 010 Y(J) = DATA(I1,J)
0073 LU = 1
0074 ID = 1
0075 WRITE (LI,107)
0076 READ (LI,149) IDUM
0077 WRITE (LI,108)
0078 READ (LI,149) IBUM

```

Figure I-3. Listing of Program to Plott Raw Data Waveforms: &WAVE.
(Continued on next page.)

```

0079 IF (IRUM.EQ. 2HPL ) ID = 2
0080 IF (ID.EQ. 2 ) LU = 13
0081 CALL PLOTTR (IGCB,ID,1,LU)
0082 CALL SETAR (IGCB,1,5)
0083 CALL VIEWP (IGCB,20.,100.,20.,68.)
0084 CALL WINDOW (IGCB,0.,256.,-1.0,1.0)
0085 IF ( IDUM.NE. 2HYE ) GOTO 015
0086 CALL FXD (IGCB,2)
0087 CALL LGRID (IGCB,-16.,.10,0.0,0.0,4.,2.,1.)
0088
015 CONTINUE
0089 CALL MOVE (IGCB,X(1),Y(1))
0090 DO 020 J = 2,256,1
0091 CALL DRAW (IGCB,X(J),Y(J))
0092 WRITE (LI,103)
0093 READ (LI,149) IDUM
0094 IF ( IDUM.EQ. 2HYE ) GOTO 05
0095 GOTO 050
0096
025 WRITE (LI,113)
0097 READ (LI,*) ICHAN
0098 WRITE (LI,114)
0099 READ (LI,*) N,IBLADE
0100 ISTART = (IBLADE-1) * 256 + 1
0101 ISTOP = ISTART + 255
0102 I1 = 0
0103 DO 035 I = ISTART,ISTOP,1
0104 I1 = I1 + 1
0105 IBLADE = I1 * 256 + 100000R
0106 CALL EXEC (3,19)
0107 CALL EXEC (1,19,IRPM,1,IBLADE)
0108 CALL EXEC (1,20,IBUFF,N,ICHAN,0)
0109 RBUFO = 0.0
0110 DO 030 J = 1,N,1
0111 IBUFF(J) = IAND(IBUFF(J),MASK)
0112 RBUFF = FLOAT(IBUFF(J))/32768.
0113 030 RBUFO = RBUFF + RBUFO
0114 035 Y(I1) = ((RBUFO*FVSULTG)/N)
0115 LU = 1
0116 ID = 1
0117 WRITE (LI,107)
0118 READ (LI,149) IDUM
0119 WRITE (LI,108)
0120 READ (LI,149) IRUM
0121 IF (IRUM.EQ. 2HPL ) ID = 2
0122 IF (ID.EQ. 2 ) LU = 13
0123 CALL PLOTTR (IGCB,ID,1,LU)
0124 CALL SETAR (IGCB,1,5)
0125 CALL VIEWP (IGCB,20.,100.,20.,68.)
0126 CALL WINDOW (IGCB,0.,256.,-1.0,1.0)
0127 IF ( IDUM.NE. 2HYE ) GOTO 040
0128 CALL FXD (IGCB,2)
0129 CALL LGRID (IGCB,-16.,.10,0.0,0.0,4.,2.,1.)
0130
040 CONTINUE
0131 CALL MOVE (IGCB,1,Y(1))
0132 DO 045 J = 2,256,1
0133 X(J) = J * 1.0
0134 045 CALL DRAW (IGCB,X(J),Y(J))
0135
050 WRITE (LI,104)
0137 READ (LI,149) IDUM
0138 IF ( IDUM.NE. 2HST ) GOTO 01
0139 STOP 7777
0140 END

```

Figure I-3. Listing of Program to Plott Raw Data Waveforms: &WAVE.

APPENDIX J

DATA REDUCTION PROGRAM &ABRED

Program &ABRED was explained almost completely in chapter 6.4. More detailed explanations shall be given in here where they are needed. Figure J-1 shows a self-explanatory flow chart of the program while Fig. J-2 is a complete listing.

From the flow chart it is obvious that the first and bigger part of the program deals with overall flow measurements from the combination probe. The data reduction of these measurements is not explained since Ref. 1 deals with this in great detail. It should be mentioned that the raw data used for the combination probe data reduction is the average of the raw data which was acquired along with the acquisition of any set of Kulite probe data. Thus the results of the combination probe represent one average flow vector which is assumed to be constant throughout the data acquisition process. As the Kulite data used for the on-line calibration is derived from the whole raw data acquired also, this seems to be a reasonable way. The principle of the on-line calibration was described in chapter 6.1 already. If a print-out of the control parameters was chosen, the result of the on-line calibration will be displayed in the form of a linear equation relating A and B probe pressures to voltages.

The results of the on-line calibration are first applied to the dc-level values from the A and B probe in order to calculate the average flow vector. Chapter 6.4 shows the results of this process. The procedure used to derive these values is in principal the same as the one used to calculate flow vector quantities for the individual measurements. In order to check the quality of the data reduction, an output of the A and B probe results as derived from their approximations can be produced. The yaw and pitch angle as well as Mach number are derived from the approximation results and printed out. These values can be compared to those derived from the combination probe (see 6.4).

Then the DO-loop for the reduction of individual data points is started at the position (ISTART) determined earlier. For any of these positions the results of the on-line calibration is applied to the raw data first, so that absolute pressure values exist. The data reduction procedure as described in 6.4 is then applied to these values. Using the local Mach number as well as the total pressure as derived from the A probe, pressure coefficients C_{pA} are derived as functions of yaw angle and can be printed if desired. The examination of these values proved to be very helpful in the evaluation of the quality of the achieved result.

Since the A probe has only one calibration curve C_{pA} as a function of yaw angle, as long as the pitch angle and Mach number do not exceed the range of the calibration, for any

measured position the same curve should be resolved. The use made of this fact so far is described in chapter 7.

When the DO-loop for all described positions is completed, the reduced data is stored in a file. Only pitch and yaw angle and Mach number (or x) are stored, since they are sufficient to describe the individual flow vectors.

<u>Common Block Identifier</u>	<u>Variable</u>
DTA2	X1, Y

<u>Variable</u>	<u>Type</u>	<u>Description</u>
AAO	Real	A probe yaw angle for aligned flow
ABO	Real	B probe yaw angle corresponding to max. probe output
ASL	Real	A probe yaw angle 63° left of flow aligned yaw angle
ASR	Real	A probe yaw angle 63° right of flow aligned yaw angle
BETA	Real	Dimensionless pressure coefficient
BETA2	Real	Relative rotor exit flow angle
COECPB(7,7)	Real	Data array for coefficients of 3-D CPOB approximation
COEF(7)	Real	Data array for 2-D approximation coefficients
COEKP(7,7)	Real	Data array for coefficients of 3-D Kulite pitch angle approximation
COEKX(7,7)	Real	Data array for coefficients of 3-D Kulite Mach number approximation
COEOP(7,7)	Real	Data array for coefficients of 3-D combination probe pitch angle approximation

<u>Variable</u>	<u>Type</u>	<u>Description</u>
COEOX(7,7)	Real	Data array for coefficients of 3-D combination probe Mach number approximation
CPA	Real	Pressure coefficient from A probe
CPAMAX	Real	Maximum pressure coefficient from A probe
CPBMAX	Real	Maximum pressure coefficient from B probe
CPOA(6)	Real	Data array for 2-D approximation of A probe pressure coefficients
DATA(20,256)	Real	Data array containing the raw data
DEAMAX	Real	First derivative of approximated function EA (voltage A probe) of yaw angle for maximum of EA
DEBMA	Real	First derivative of approximated function EB (voltage B probe) of yaw angle for maximum of EB
DELTA	Real	Pressure coefficient
DP	Real	Pressure difference for two pressure values corresponding to two yaw angles which are separated by DX
DPA	Real	Difference between actual A probe pressure and value derived from polynomial approximation at each yaw position.
DPB	Real	Difference between actual B probe pressure and value derived from polynomial approximation at each yaw position
DPX	Real	First derivative of the function $P_A(\alpha) - P_A(\alpha - \Delta\alpha)$
DX	Real	Given spread in yaw angle between PSAL and PSAR
EAMAX	Real	Maximum voltage from the A probe
EBMAX	Real	Maximum voltage from the B probe

<u>Variable</u>	<u>Type</u>	<u>Description</u>
EQ3	Real	CPOA - maximum pressure coefficient of A probe (used in on-line calibration)
EQ5	Real	CPOB - maximum pressure coefficient of B probe (used in on-line calibration)
GAMMA	Real	Pressure coefficient
ICR	Integer	Cartridge reference number
IDCB(144)	Integer	Data control block
IDCBS	Integer	Control block length (of IDCB)
IFILE(3)	Integer	Array containing file name
IL	Integer	Total number of words read from data file (two words for one value)
IPRINT	Integer	Decision variable (control parameters yes or no?)
IPRIN1	Integer	Decision variable (calibration coefficients yes or no?)
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions
ITYPE	Integer	Type of data file
ICLR(3)	Integer	Command to clear line above cursor
LI	Integer	Input device number
LO	Integer	Output device number
NOLF	Integer	No line feed command
NOCR	Integer	No carriage return command
PA(9)	Real	A probe pressure values from individual measurements
PAA(9)	Real	A probe pressure values from averaged (dc-level) measurements
PAB(9)	Real	B probe pressure values from averaged (dc-level) measurements

<u>Variable</u>	<u>Type</u>	<u>Description</u>
PAC(9)	Real	Calculated values of A probe
PAMAX	Real	Maximum pressure value of A probe output as function of yaw angle
PB(9)	Real	B probe pressure values from individual measurements
PBARO	Real	Barometric pressure
PBC	Real	Calculated values of B probe
PBMAX	Real	Maximum pressure value of B probe output as function of yaw angle
PHI	Real	Pitch angle
PKB	Real	Maximum absolute average value of B probe pressure
PREF	Real	Average value of Kulite reference pressure
PREFP(9)	Real	Array of reference pressures for all 9 independent yaw positions
PSA	Real	Static pressure equivalent of A probe
PSAL	Real	Pressure reading of A probe for a yaw angle 63° to the left of the flow aligned yaw angle
PSAR	Real	Pressure reading of A probe for a yaw angle 63° to the right of the flow aligned yaw angle
PSTAT	Real	Static pressure
PSTATA	Real	Static pressure minus Kulite reference pressure
PTOTAL	Real	Total pressure
POA	Real	Maximum pressure output of A probe (on-line calibration)
POB	Real	Maximum pressure output of B probe (on-line calibration)

<u>Variable</u>	<u>Type</u>	<u>Description</u>
P1	Real	
P23	Real	Pressure values of combination probe
P4	Real	
RADIS	Real	Radius of probe tip location
RDATA(3,256)	Real	Reduced data array
RPM	Real	Compressor speed
SECTA	Real	Intercept A probe
SECTB	Real	Intercept B probe
SLOPEA	Real	Slope A probe
SLOPEB	Real	Slope B probe
TT2	Real	Total temperature at rotor exit
U	Real	Circumferential rotor speed
XM	Real	Mach number
XU	Real	Dimensionless circumferential rotor speed
XVEL	Real	Mach number equivalent dimensionless speed
X0	Real	Starting value for the iteration to find PSAL and PSAR
X1(256)	Real	Data array for 2-D approximations
Y(256)	Real	Data array for 2-D approximations
YAW	Real	Yaw angle
YAWA(9)	Real	Array containing A probe yaw angles
YAWB(9)	Real	Array containing B probe yaw angles

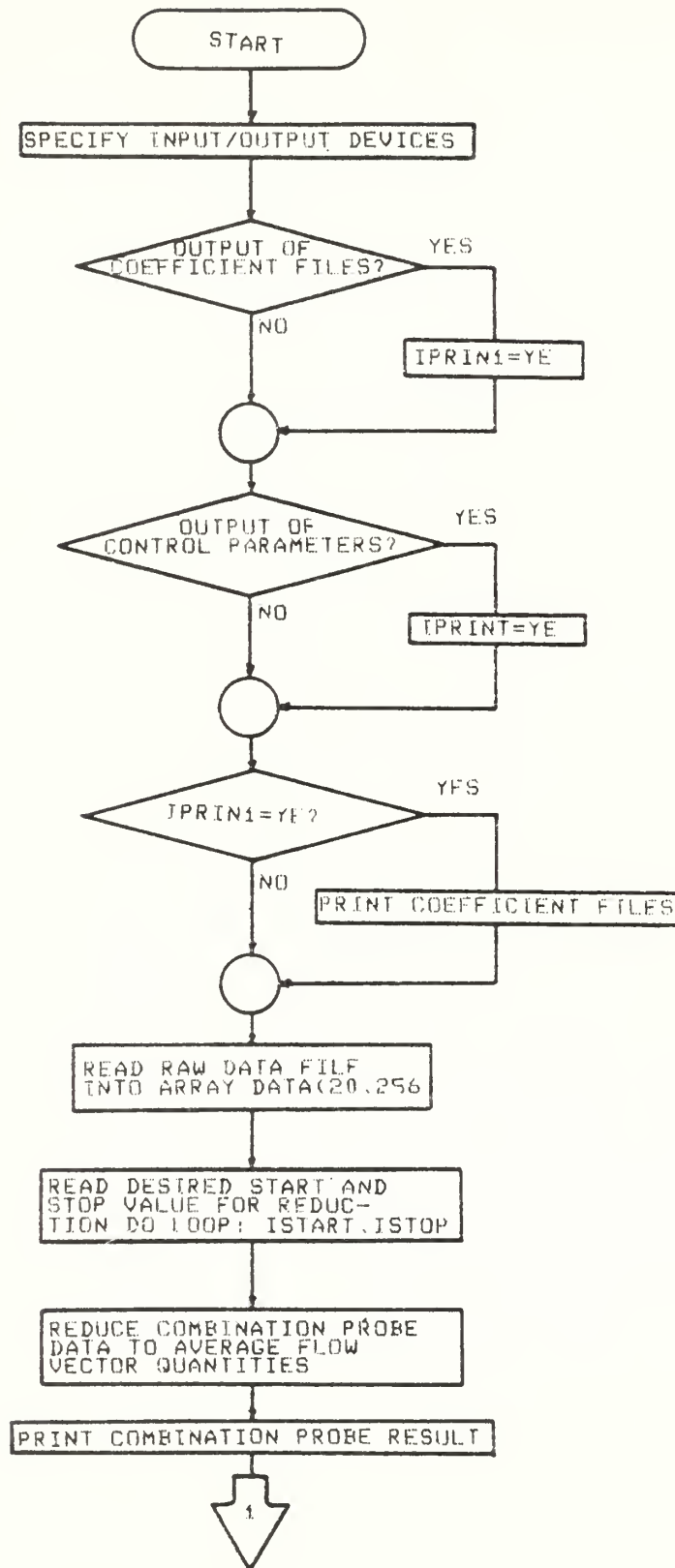


Figure J-1. Flow Chart of Data Reduction Program &ABRED.

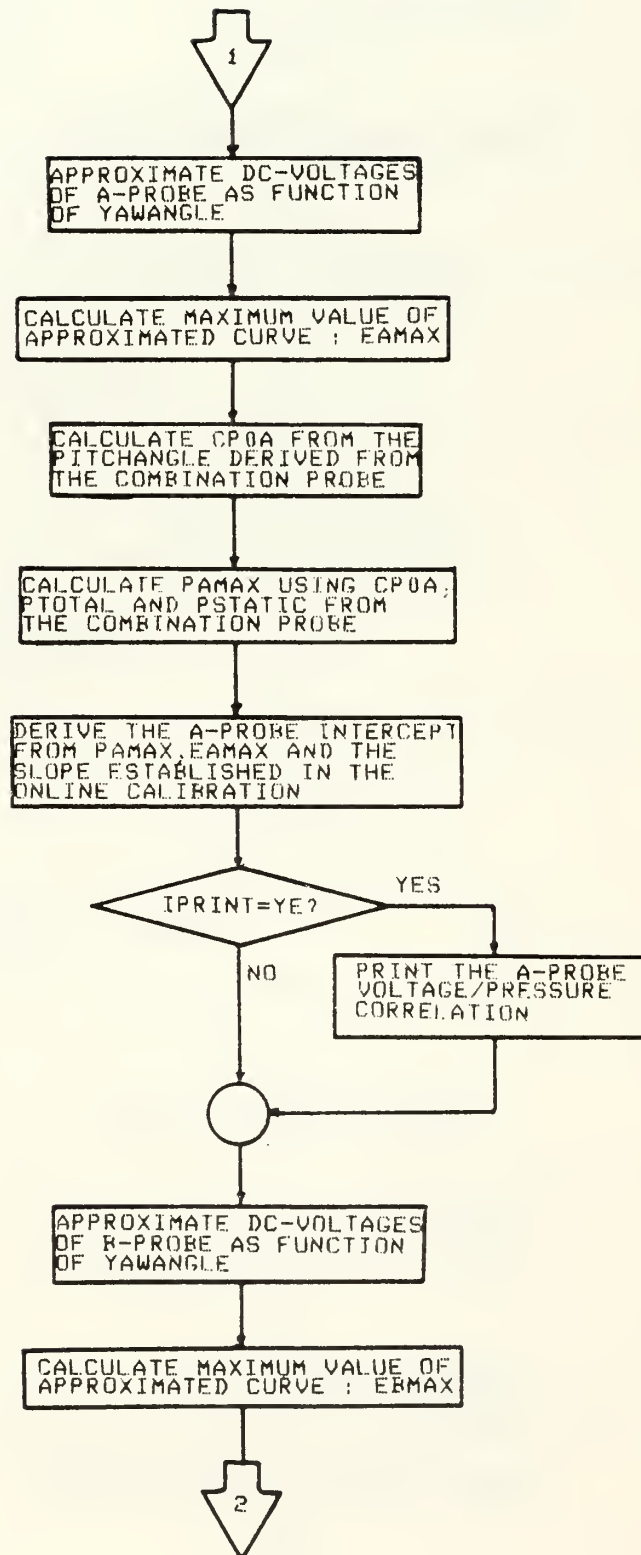


Figure J-1. Flow Chart of Data Reduction Program SABRED.

con't

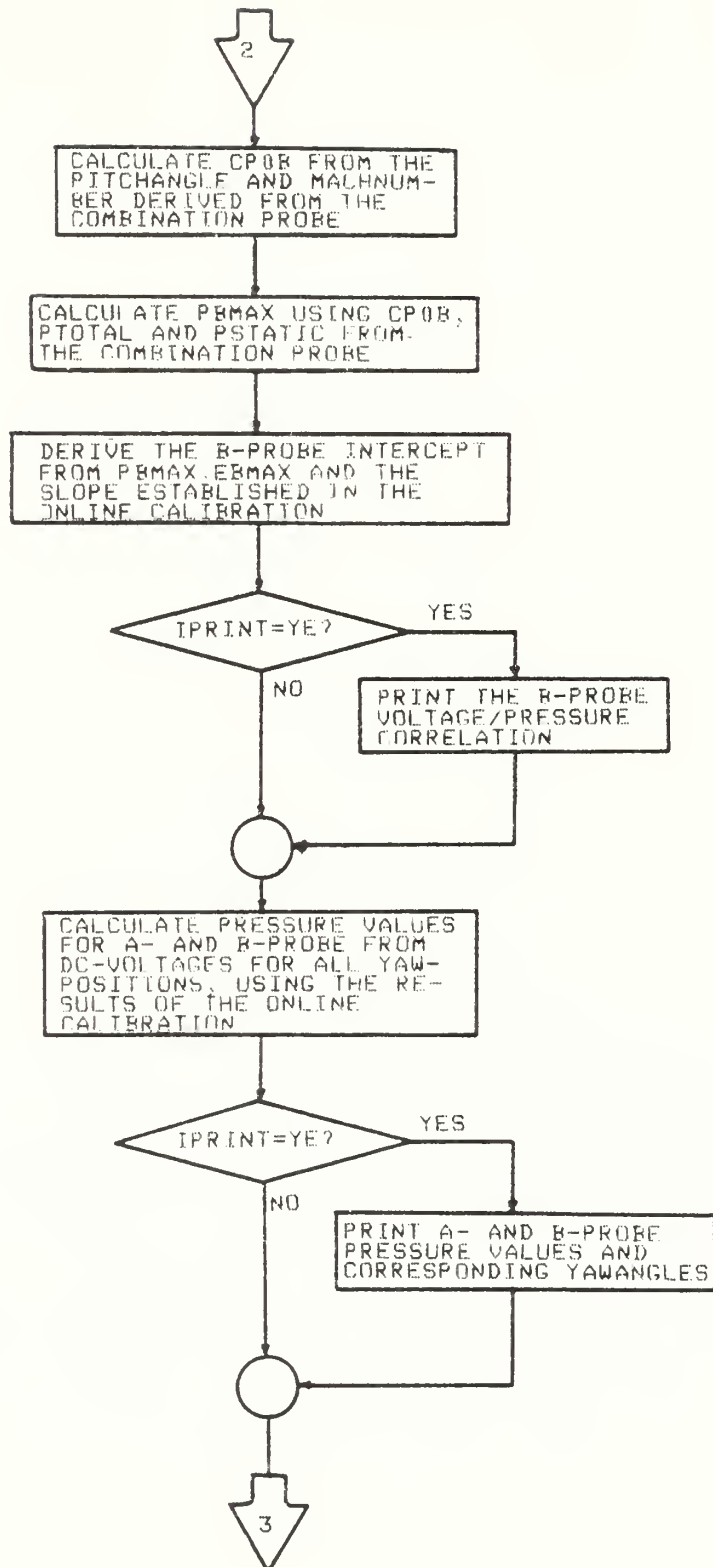


Figure J-1. Flow Chart of Data Reduction Program &ABRED.

con't

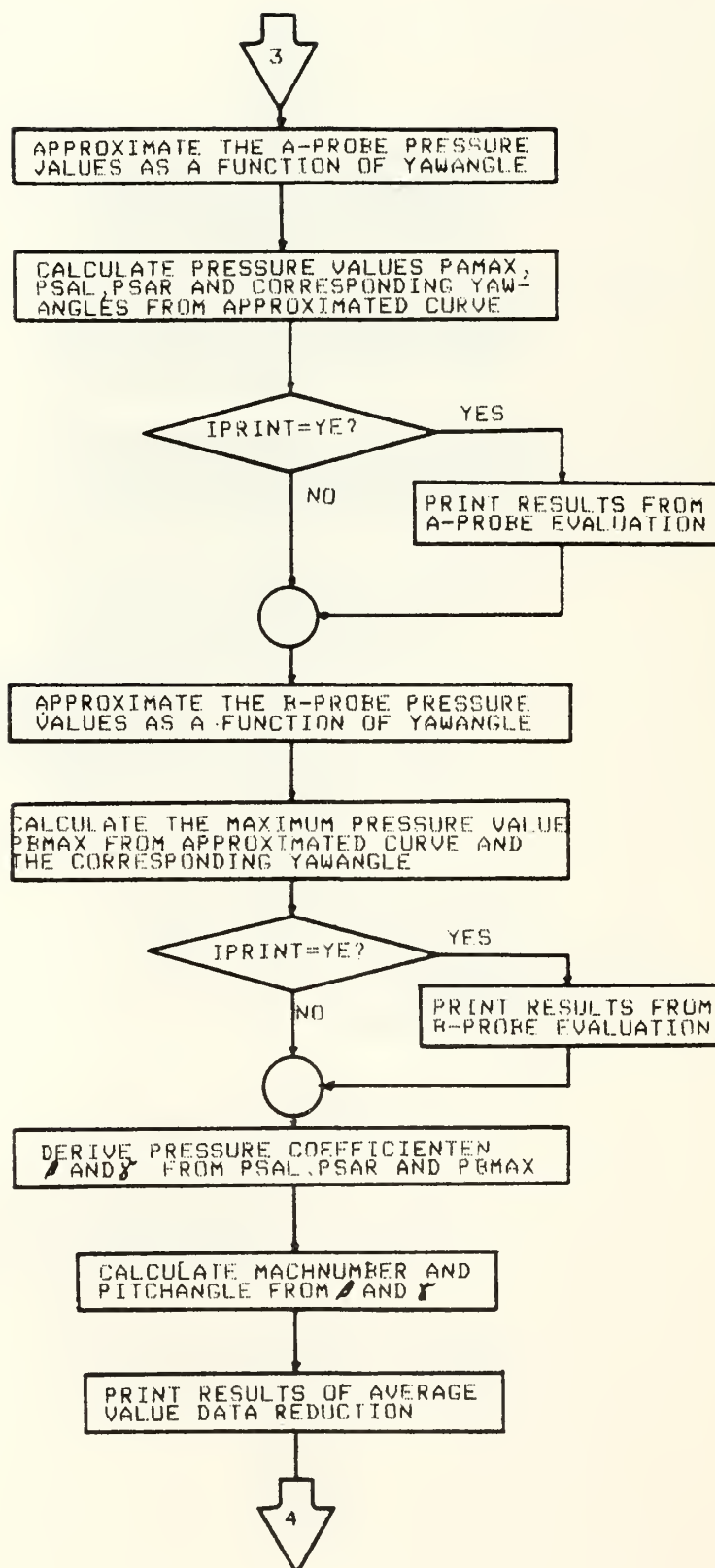


Figure J-1. Flow Chart of Data Reduction Program SABRED.

con't

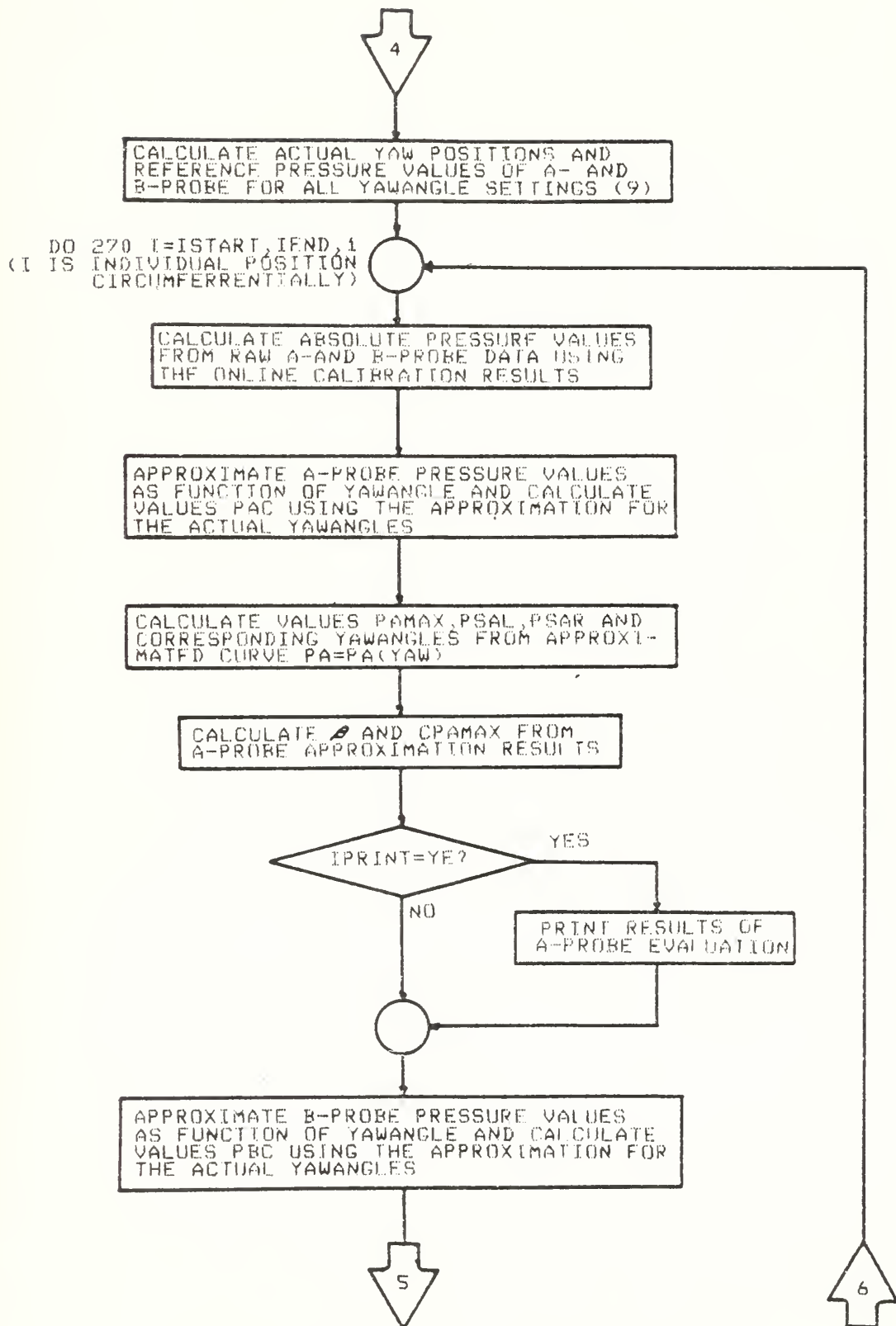


Figure J-1. Flow Chart of Data Reduction Program &ABRED.

con't

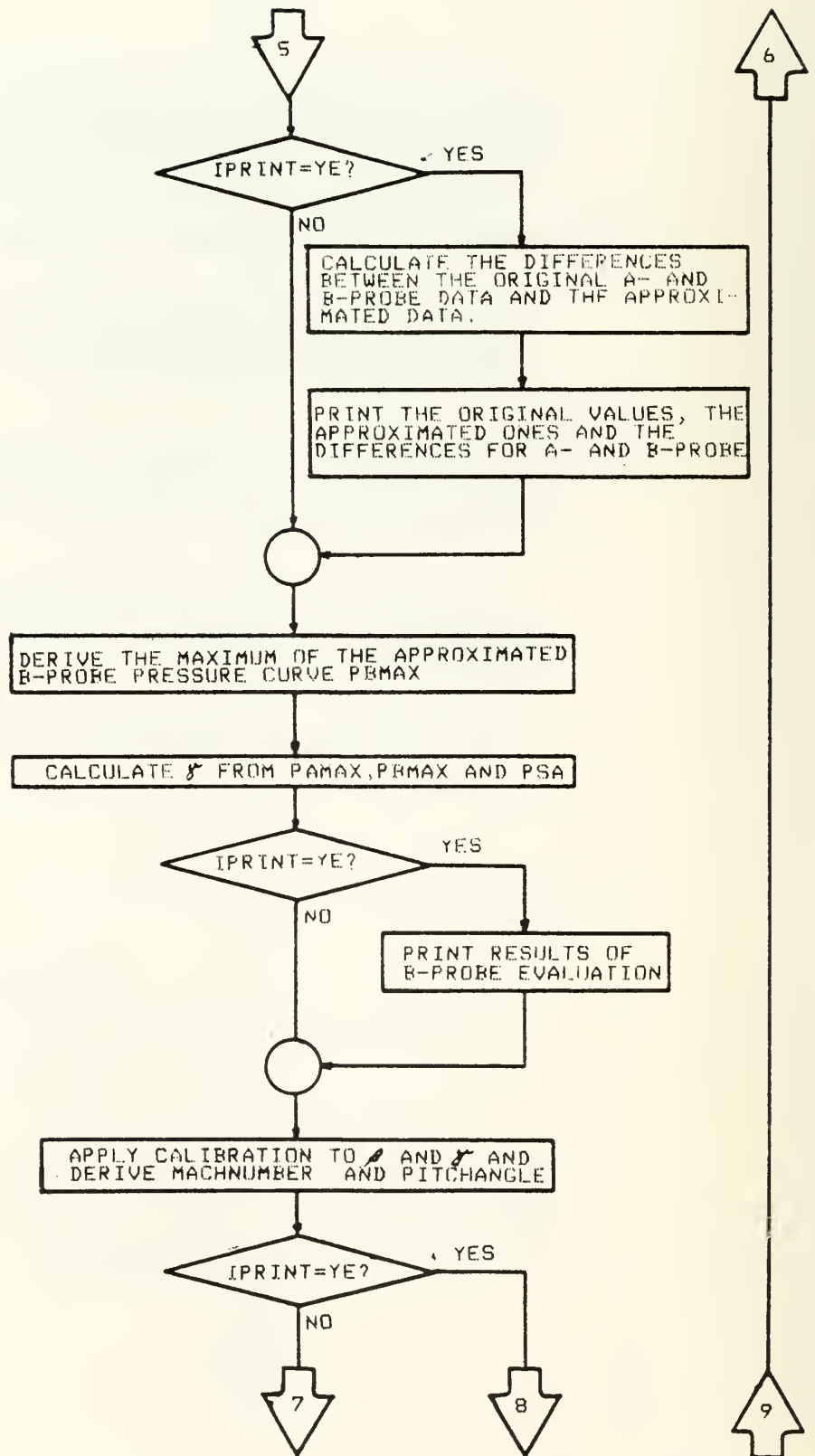


Figure J-1. Flow Chart of Data Reduction Program &ABRED.

con't

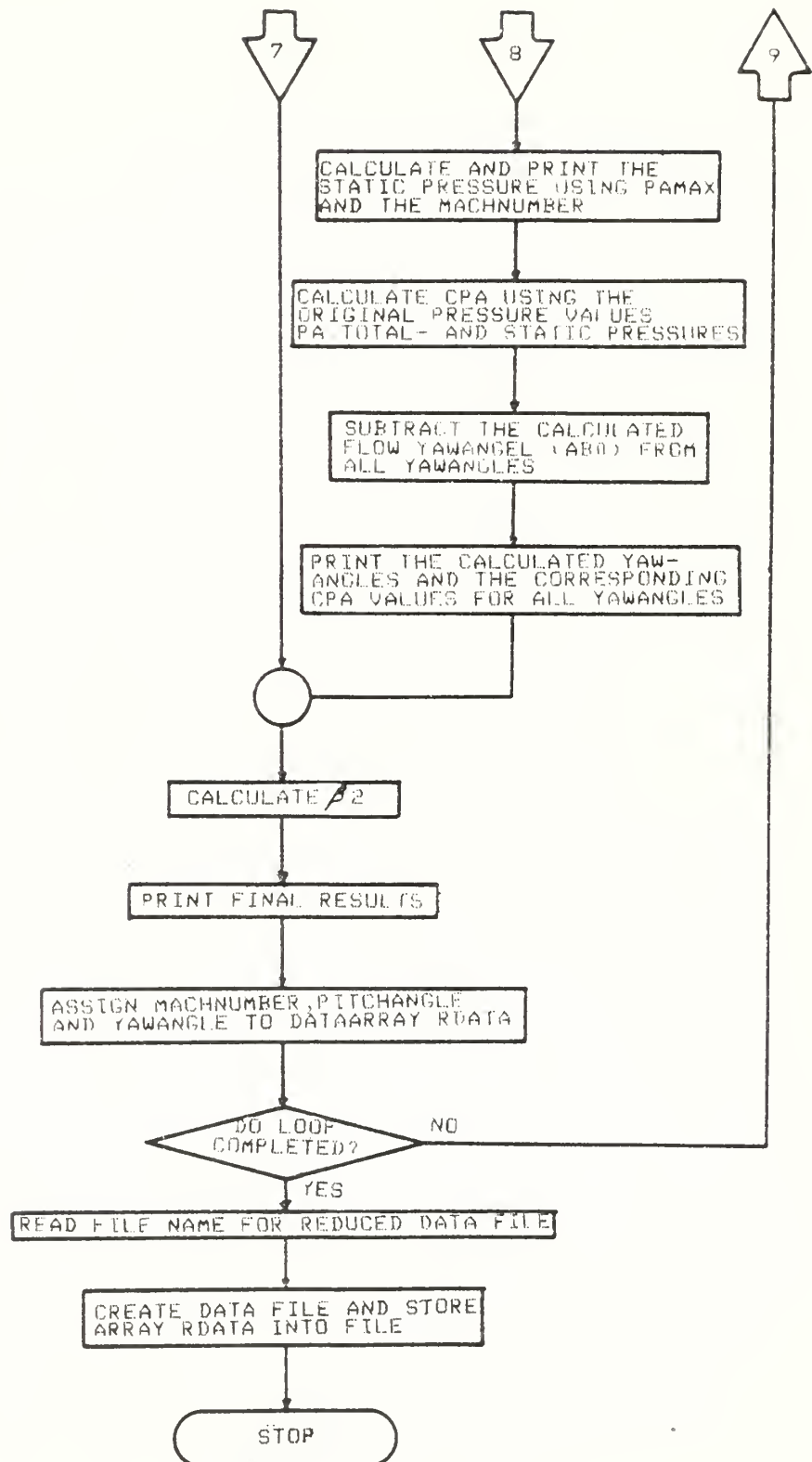


Figure J-1. Flow Chart of Data Reduction Program &ABRED.
con't

&ABRED T=00004 IS ON CR00027 USING 00142 BLKS R=0000

```

0001 FTN4,L
0002 PROGRAM ABRED (3,99)
0003 .....
0004 .....
0005 .....
0006 .....
0007 .....
0008 .....
0009 .....
0010 .....
0011 .....
0012 .....
0013 .....
0014 .....
0015 .....
0016 .....
0017 .....
0018 .....
0019 .....
0020 .....
0021 .....
0022 .....
0023 .....
0024 .....
0025 .....
0026 .....
0027 .....
0028 .....
0029 .....
0030 .....
0031 .....
0032 .....
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0037 .....
0038 .....
0039 .....
0040 .....
0041 .....
0042 .....
0043 .....
0044 .....
0045 .....
0046 .....
0047 .....
0048 .....
0049 .....
0050 .....
0051 .....
0052 .....
0053 .....
0054 .....
0055 .....
0056 .....
0057 .....
0058 .....
0059 .....
0060 .....
0061 .....
0062 .....
0063 .....
0064 .....
0065 .....
0066 .....
0067 .....
0068 .....
0069 .....
0070 .....
0071 .....
0072 .....
0073 .....
0074 .....
0075 .....
0076 .....
0077 .....
0078 .....

THIS IS PROGRAM ABRED(uction) FOR THE A-B PROBE SYSTEM.

IN THIS VERY VERSION THE PROGRAM IS SET UP FOR THE NEW A-B-
PROBES (0.063" O.D., SCREEN WITH HOLES ON A CIRCLE ).

IF ANY OTHER PROBES (KULITE AS WELL AS COMBINATION PROBE)
SHALL BE USED, THE CORRECT FILE NAMES FOR THE COEFFICIENT
FILES HAVE TO BE PUT IN :

FILE # CONTAINS APPROX. COEFFICIENTS: DATA ARRAY NAME

1 KULITE PROBES MACHNUMBER COEKK
2 KULITE PROBES PITCHANGLE COEKP
3 KULITE PROBES CP0B COECP
4 COMBINATION PROBE MACHNUMBER COEOK
5 COMBINATION PROBE PITCHANGLE COEOP

COMMON / DTA2 / X1,Y
REAL DATA(20,256),X1(256),Y(256),COEF(7)
REAL COEOK(7,7),COEOP(7,7),COEKK(7,7),COEKP(7,7),COECP(7,7)
REAL PAA(9),PAR(9),YAWA(9),YAWB(9)
REAL PA(9),PR(9),PAC(9),PREFP(9)
REAL RDATA(3,256)
CP0A(6)
DIMENSION
INTEGER IDCBS(144),IFILE(3),ISIZE(2)
INTEGER NOLC,NOCRI(2),ICLR(3)
DATA CP0A(1) / 1.0025921 /
DATA CP0A(2) / 0.0356475 /
DATA CP0A(3) / -2724224 /
DATA CP0A(4) / 0.9320285 /
DATA CP0A(5) / -2.333180 /
DATA CP0A(6) / 0.0000000 /
DATA IDCBS / 144 /
DATA ITYPE / 1 /
DATA ICLR / 015524B,015515B,006537B /
DATA NOLC / 006537B /

300 FORMAT (" OUTPUT INPUT DATA TO ANY OTHER DEVICE? ENTER NO
* OR LU# 1"/" "A2)
305 FORMAT (I2)
310 FORMAT (" DO YOU WANT AN OUTPUT OF THE CALIBRATION COEFFICIENTS?"
*/" ENTER YES IF SO OR ANYTHING ELSE IF NOT!"/" "A2)
315 FORMAT (" DO YOU WANT AN OUTPUT OF THE CONTROLL PARAMETERS?"/" KE
*Y YES IF SO OR ANYTHING ELSE IF NOT!"/" "A2)
320 FORMAT (// " THE DATA READ FROM FILE "3A2" ARE"/)
325 FORMAT (" 1 /" "F11.6)
330 FORMAT (" I3,7(1X,F11.6)
335 FORMAT (" ENTER RAW DATA FILE!"/
* " DON'T FORGET SECURITY CODE & CARTRIDGE REFERENCE NUMBER!"/
* " "A2)
340 FORMAT ((3A2),1X,I2,1X,I2)
345 FORMAT (" ENTER THE NUMBER OF THE START AND END POSITION :"/
* " "A2)
350 FORMAT (I3,1X,I3)
355 FORMAT (" *****"/
* " RAW DATA FILE : "3A2": "I3" /
* " *****"/)
360 FORMAT(/" FLOW AVERAGED VALUES AS ESTABLISHED WITH THE COMBINATION
* PROBE"/" Ptotal(INCH H2O) Pstatic(INCH H2O)"6X"Xvel"6X"Mach"2X"
*Phi(deg)"2X"Yaw(deg)"2(5X,F13.6),2(2X,F8.5),2(3X,F7.2)/)
365 FORMAT (" EQUATION FOR A-PROBE PRESSURE :"/" PA = "F12.6" + " F12.
*6" * VOLTAGE(raw)*0.01 + PREF(INCH H2O)")
370 FORMAT(" CP0A = "F10.5" CP0B = "F10.7)
375 FORMAT(" EQUATION FOR B-PROBE PRESSURE :"/" PB = "F12.6" + " F12.
*6" * VOLTAGE(raw)*0.01 + PREF(INCH H2O)")
380 FORMAT (/ " # PAA(#) PAR(#) YAWA(#) YAWB(#)"/)
385 FORMAT(I2,4(1X,F7.5))
390 FORMAT(" A-PROBE APPROXIMATION RESULTS : YAW = "3(5X,F9.2)/16X" PR
*ESSURE (INCH H2O) = "3(3X,F11.6)/29X" CPAMAX = "F8.4/)
395 FORMAT(/" B-PROBE APPROXIMATION RESULTS : YAW0 = "F5.1" PRESSURE
*(INCH H2O) = "F6.2//)
400 FORMAT(" AVERAGE VALUE RESULTS FROM THE A-B SYSTEM:"//5X"BETA"4X"G
*AMMA"5X"Xvel"4X"Pitch"6X"Yaw"7X"XU"6X"XAX"4X"BETA2"/3(F9.5),2(2X,F
*7.2),2(F9.5),2X,F7.2)

```

Figure J-2. Listing of Data eduction Program &ABRED.
(Continued on next page.)


```

0159      JJ = 5
0160      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0161      CALL CLOSE (IDCB,IERR,0)
0162      JJ = 6
0163      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0164      IF (IPRIN1 .NE. 2HYE) GOTO 035
0165      .....
0166      : OUTPUT INPUT DATA.
0167      :
0168      :
0169      :
0170      WRITE (LI, 320) IFILE
0171      IF ( LO .NE. 0 ) WRITE (LO, 320) IFILE
0172      WRITE (LI, 325) (I1,I1=1,7)
0173      IF ( LO .NE. 0 ) WRITE (LO, 325) (I1,I1=1,7)
0174      DO 030 I1=1,7,1
0175      IF ( LO .NE. 0 ) WRITE (LO, 330) I1,(COEKP(I1,J1),J1=1,7,1)
0176      030 WRITE (LI, 330) I1,(COEKP(I1,J1),J1=1,7,1)
0177      .....
0178      :
0179      : READ COEFFICIENTFILE FOR THE KULITE CP0B APPROXIMATION
0180      : FROM DISC INTO ARRAY COECP(7,7).
0181      :
0182      :
0183      035 IFILE(1) = 2HMI
0184      IFILE(2) = 2HST
0185      IFILE(3) = 2HCP
0186      CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
0187      JJ = 7
0188      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0189      CALL READF (IDCB,IERR,COECP,98,LEN,1)
0190      JJ = 8
0191      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0192      CALL CLOSE (IDCB,IERR,0)
0193      JJ = 9
0194      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0195      IF (IPRIN1 .NE. 2HYE) GOTO 045
0196      .....
0197      : OUTPUT INPUT DATA.
0198      :
0199      :
0200      :
0201      WRITE (LI, 320) IFILE
0202      IF ( LO .NE. 0 ) WRITE (LO, 320) IFILE
0203      WRITE (LI, 325) (I1,I1=1,7)
0204      IF ( LO .NE. 0 ) WRITE (LO, 325) (I1,I1=1,7)
0205      DO 040 I1=1,7,1
0206      IF ( LO .NE. 0 ) WRITE (LO, 330) I1,(COECPB(I1,J1),J1=1,7,1)
0207      040 WRITE (LI, 330) I1,(COECPB(I1,J1),J1=1,7,1)
0208      .....
0209      :
0210      : READ COEFFICIENTFILE FOR THE COMBINATIONPROBE MACHNUMBER
0211      : APPROXIMATION INTO ARRAY COEOX(7,7).
0212      :
0213      :
0214      045 ICR = 28
0215      IFILE(1) = 2HCO
0216      IFILE(2) = 2HEF
0217      IFILE(3) = 2H2X
0218      CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
0219      JJ = 10
0220      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0221      CALL READF (IDCB,IERR,COEOX,98,LEN,1)
0222      JJ = 11
0223      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0224      CALL CLOSE (IDCB,IERR,0)
0225      JJ = 12
0226      IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
0227      IF (IPRIN1 .NE. 2HYE) GOTO 055
0228      .....
0229      : OUTPUT INPUT DATA.
0230      :
0231      :
0232      :
0233      WRITE (LI, 320) IFILE
0234      IF ( LO .NE. 0 ) WRITE (LO, 320) IFILE
0235      WRITE (LI, 325) (I1,I1=1,7)
0236      IF ( LO .NE. 0 ) WRITE (LO, 325) (I1,I1=1,7)
0237      DO 050 I1=1,7,1
0238      IF ( LO .NE. 0 ) WRITE (LO, 330) I1,(COEOX(I1,J1),J1=1,7,1)

```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```

239 050 WRITE (LI, 330) I1,(COEOX(I1,J1),J1=1,7,1)
240 .....
241 .....
242 : READ COEFFICIENTFILE FOR THE COMBINATIONPROBE PITCHANGLE
243 : APPROXIMATION INTO ARRAY COEOP(7,7).
244 .....
245 .....
246 055 IF (FILE(1) = 2HCO)
247 IF (FILE(2) = 2HEF)
248 IF (FILE(3) = 2H3P)
249 CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
250 JJ = 13
251 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
252 CALL READF (IDCB,IERR,COEOP,98,LEN,1)
253 JJ = 14
254 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
255 CALL CLOSE (IDCB,IERR,0)
256 JJ = 15
257 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
258 IF (IPRIN1 .NE. 2HYE) GOTO 065
259 .....
260 : OUTPUT INPUT DATA.
261 .....
262 .....
263 .....
264 WRITE (LI,320) IFILE
265 IF (LO.NE.0) WRITE (LO,320) IFILE
266 WRITE (LI,325) (I1,I1=1,7)
267 IF (LO.NE.0) WRITE (LO,325) (I1,I1=1,7)
268 DO 060 I1=1,7,1
269 IF (LO.NE.0) WRITE (LO,330) I1,(COEOP(I1,J1),J1=1,7,1)
270 060 WRITE (LI,330) I1,(COEOP(I1,J1),J1=1,7,1)
271 .....
272 .....
273 065 WRITE (LI,335) NOLF
274 READ (LI,340) IFILE,ISECU,ICR
275 WRITE (LI,1149) (ICLR,I1=1,3)
276 IL = 10240
277 ISIZE(1) = 80
278 ISIZE(2) = 128
279 CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
280 JJ = 13
281 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
282 CALL READF (IDCB,IERR,DATA,IL,LEN,1)
283 JJ = 14
284 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
285 CALL CLOSE (IDCB,IERR,0)
286 JJ = 15
287 IF ( IERR .LT. 0 ) WRITE (LI,1111) JJ,IERR
288 WRITE (LI,345) NOLF
289 READ (LI,350) ISTART,IEND
290 WRITE (LI,355) IFILE,ICR
291 IF (LO.NE.0) WRITE (LO,355) IFILE,ICR
292 .....
293 .....
294 : COMBINATION PROBE DATA REDUCTION.
295 .....
296 .....
297 P1 = 0.0
298 P23 = 0.0
299 P4 = 0.0
300 PREF = 0.0
301 RPM = 0.0
302 RADIS = 0.0
303 YAW = 0.0
304 TT2 = 0.0
305 DO 070 I = 1,9,1
306 J = (I-1) * 20
307 PRARD = DATA(20,J+7)*1.3585
308 P1 = P1 + (DATA(20,J+3) - DATA(20,J+1) - PRARD)*100*1000
309 P23 = P23 + (DATA(20,J+4) - DATA(20,J+1) + PRARD)*100*1000
310 P4 = P4 + (DATA(20,J+5) - DATA(20,J+1) + PRARD)*100*1000
311 PREF = PREF + DATA(20,J+14) * 100 * 1000
312 RPM = RPM + DATA(20,J+6) * 10
313 RADIS = RADIS + (DATA(20,J+8)+DATA(20,J+10)+DATA(20,J+12))/3*1000
314 YAW = YAW + DATA(20,J+9) * 10000
315 070 TT2 = TT2 + (DATA(20,J+15) + DATA(20,J+16)) * 1000
316 P1 = P1 / 9
317 P23 = P23 / 9
318 P4 = P4 / 9

```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```

319     PREF      = PREF / 9
320     RPM        = RPM / 9
321     RADIS      = RADIS / 9
322     RADIS      = 5.51 - RADIS
323     YAW        = YAW / 9
324     TT2        = TT2 / 9
325     TT2        = 31.9557 + 30.6827 * TT2 - 0.3679 * TT2 * TT2
326     TT2        = ((TT2 - 32) * 5 / 9) + 273.15
327     VT2        = SQRT ( 2008 * TT2 )
328     U          = (RPM / 60) * RADIS * 2 * 3.14159 * 0.0254
329     XU         = U / VT2
330     BETA       = ( P1 - P23 ) / P1
331     GAMMA      = ( P1 - P4 ) / ( P1 - P23 )
332     DELTA      = GAMMA * BETA
333
334     XVEL       = 0.0
335     PHI        = 0.0
336     DO 075 I1 = 1,2,1
337     DO 075 I2 = 1,2,1
338     XVEL       = XVEL + (COEOX(I1,I2)*DELTA**((I2-1))*GAMMA**((I1-1))
339     PHI        = PHI + (COEOP(I1,I2)*DELTA**((I2-1))*GAMMA**((I1-1))
340     XM         = SQRT ((2/(1.402-1))*((XVEL*XVEL)/(1-(XVEL*XVEL))))
341     PTOTAL     = P1
342     PSTAT      = PTOTAL * (1-XVEL*XVEL)**(1.402/.402)
343     WRITE (LI,360) PTOTAL,PSTAT,XVEL,XM,PHI,YAW
344     IF ( LO .NE. 0 ) WRITE (LO,360) PTOTAL,PSTAT,XVEL,XM,PHI,YAW
345     .....
346     C
347     C
348     C
349     C
350     C
351     C
352     C
353     C
354     C
355     C
356     DO 080 I = 1,2,1
357     J          = (I-1) * 20
358     X1(I)      = DATA(20,J+11) * 10000 * 3.14159 / 180
359     Y(I)       = DATA(20,J+17)
360     CALL MAT2 (9,5,COEF,-4)
361     C
362     C
363     C
364     C
365     C
366     X0         = 0.4
367     085 DEAMAX = FND (4,COEF,X0)
368     IF (ABS(DEAMAX) .LT. 0.0001 ) GOTO 090
369     X0 = X0 - DEAMAX / (2*COEF(3)+6*COEF(4)*X0+12*COEF(5)*X0*X0)
370     GOTO 085
371     090 EAMAX  = FNP (4,COEF,X0)
372     SLOPEA    = (DATA(1,160) + DATA(1,180))/(-2.0)*100*1000
373     PHI       = PHI * 3.14159 / 180.
374     C
375     C
376     C
377     C
378     C
379     EQ3       = FNP (4,CP0A,PHI)
380     PAMAX     = EQ3 * (PTOTAL-PSTAT) + PSTAT
381     SECTA     = PAMAX - PREF - SLOPEA * EAMAX
382     POA       = SECTA + SLOPEA * EAMAX + PREF
383     IF ( IPRINT .NE. 2HYES ) GOTO 095
384     WRITE (LI,365) SECTA,SLOPEA
385     IF ( LO .NE. 0 ) WRITE (LO,365) SECTA,SLOPEA
386     095 CONTINUE
387     C
388     C
389     C
390     C
391     C
392     C
393     C
394     DO 100 I = 1,8,1
395     J          = (I-1) * 20
396     X1(I)      = DATA(20,J+13) * 10000 * 3.14159 / 180
397     Y(I)       = DATA(20,J+18)
398     CALL MAT2 (8,5,COEF,-4)

```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```

0399 C : INITIAL ESTIMATE FOR THE APPROXIMATION IS : YAW = 0 (deg)
0400 C :
0401 C :
0402 C :
0403 C :
0404 X0 = 0.0
105 DEBMA = FNP (4, COEF, X0)
0405 IF (ABS(DEBMA) .LT. 0.00001) GOTO 110
0406 X0 = X0 - DEBMA / (2*COEF(3)+6*COEF(4)*X0+12*COEF(5)*X0*X0)
0407 GOTO 105
0408 EMAX = FNP (4, COEF, X0)
0409 PSTATA = PSTAT - PREF
0410 EQS = 0.0
0411 C :
0412 C :
0413 C : CALCULATE CP0B FROM COMBINATION PROBE RESULTS.
0414 C :
0415 C :
0416 DO 115 I1 = 1, 5, 1
0417 DO 115 J1 = 1, 5, 1
115 EQS = EQS + (COECPB(I1, J1)*XVEL**(J1-1))*PHI**(I1-1)
0418 WRITE (LI, 370) EQ3, EQS
0419 IF (LO .NE. 0) WRITE (LO, 370) EQ3, EQS
0420 P0B = EQS * (PTOTAL-PSTAT) + PSTAT
0421 PKB = P0B + PREF
0422 SLOPEB = (DATA(1, 170) + DATA(1, 190)) / (-2.0) * 100*1000
0423 SECTR = PKB - PREF - SLOPEB * EBMAX
0424 IF (IPRINT .NE. 2HYE) GOTO 120
0425 WRITE (LI, 375) SECTR, SLOPEB
0426 IF (LO .NE. 0) WRITE (LO, 375) SECTR, SLOPEB
0427 120 CONTINUE
0428 C :
0429 C :
0430 C :
0431 C :
0432 C : START DATA REDUCTION.
0433 C : FIRST CALCULATE THE AVERAGE FLOW PARAMETERS USING THE
0434 C : OVERALL VALUES FROM THE A AND B PROBE AND THE JUST
0435 C : ESTABLISHED CALIBRTION.
0436 C :
0437 C :
0438 DO 125 I = 1, 9, 1
0439 J = (I-1) * 20
0440 PAA(I) = DATA(20, J+17)
0441 PAB(I) = DATA(20, J+18)
0442 PAA(I) = SECTA + SLOPEA * PAA(I) + DATA(20, J+14)*100*1000
0443 PAB(I) = SECTR + SLOPER * PAB(I) + DATA(20, J+14)*100*1000
0444 YAWA(I) = DATA(20, J+11) * 10000
0445 YAWB(I) = DATA(20, J+13) * 10000
125 IF (IPRINT .NE. 2HYE) GOTO 135
0446 WRITE (LI, 380)
0447 IF (LO .NE. 0) WRITE (LO, 380)
0448 DO 130 I = 1, 9, 1
0449 WRITE (LI, 385) I, PAA(I), PAB(I), YAWA(I), YAWB(I)
0450 IF (LO .NE. 0) WRITE (LO, 385) I, PAA(I), PAB(I), YAWA(I), YAWB(I)
130 135 CONTINUE
0451 C :
0452 C :
0453 C :
0454 C :
0455 C : APPROXIMATE A-PROBE PRESSURES.
0456 C :
0457 C :
0458 DO 140 I = 1, 9, 1
0459 X1(I) = YAWA(I)
140 Y(I) = PAA(I)
0460 CALL MAT2 (9, 5, COEF, -4)
0461 C :
0462 C :
0463 C :
0464 C : FIND MAX. OUTPUT OF A PROBE.
0465 C :
0466 C :
0467 DX = 126.0
0468 X0 = -40.0
145 DP = (FNP(4, COEF, X0) - FNP(4, COEF, (X0+DX)))
0469 IF (ABS(DP) .LT. 0.0001) GOTO 150
0470 DPX = -2.0*COEF(3)*DX-6.0*COEF(4)*X0*DX-3.0*COEF(4)*DX*DX-
0471 * 12.0*COEF(5)*X0*X0*DX-12*COEF(5)*X0*DX*DX-4.0*COEF(5)*DX**3
0472 X0 = X0 - DP / DPX
0473 GOTO 145
0474 150 ASL = X0
0475 ASR = X0 + DX
0476 AA0 = X0 + DX / 2.0
0477 PAMAX = FNP(4, COEF, AA0)
0478

```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)

```

1479 PSAL = FNP(4,COEF,ASL)
1480 PSAR = FNP(4,COEF,ASR)
1481 PSA = (PSAL + PSAR) / 2.0
1482
1483 BETA = (PAMAX - PSA) / PAMAX
1484 CPAMAX = (PAMAX - PSA) / (PTOTAL - PSA)
1485 IF ( IPRINT .NE. 2HYES ) GOTO 155
1486 WRITE (LI,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
1487 IF (LO .NE. 0) WRITE (LO,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
1488 155 CONTINUE
1489 .....
1490 : APPROXIMATE B PROBE PRESSURES.
1491 :
1492 .....
1493 DO 160 I = 1,9,1
1494 X1(I) = YAWB(I)
1495 160 Y(I) = PAH(I)
1496 CALL MAT2 (9,5,COEF,-4)
1497 .....
1498 : FIND MAXIMUM OUTPUT OF B-PROBE.
1499 :
1500 .....
1501 X0 = 0.00
1502 DPX = FND(4,COEF,X0)
1503 165 IF ( ABS(DPX) .LT. 0.00001 ) GOTO 170
1504 X0 = X0 - DPX / (2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
1505 GOTO 165
1506 170 AB0 = X0
1507 PRMAX = FNP(4,COEF,AB0)
1508 IF ( IPRINT .NE. 2HYES ) GOTO 175
1509 WRITE (LI,395) AB0,PRMAX
1510 IF (LO .NE. 0) WRITE (LO,395) AB0,PRMAX
1511 175 CONTINUE
1512 CPRMAX = (PRMAX - PSA) / (PTOTAL - PSA)
1513 GAMMA = (CPAMAX - CPRMAX) / CPAMAX
1514 XVEL = 0.0
1515 PHI = 0.0
1516 DO 180 I1 = 1,2,1
1517 DO 180 I2 = 1,2,1
1518 XVEL = XVEL + (COEKP(I1,I2) * GAMMA** (I2-1)) * BETA** (I1-1)
1519 PHI = PHI + (COEKP(I1,I2) * GAMMA** (I2-1)) * BETA** (I1-1)
1520 180 PHI = PHI * 180 / 3.14159
1521 XAX = XVEL * COS(PHI*3.14159/180) * COS(AB0*3.14159/180)
1522 BETA2 = ATAN((XU-XVEL)*COS(PHI*3.14159/180)*SIN(AB0*3.14159/180))
1523 * / XAX) * 180 / 3.14159
1524 WRITE (LI,400) BETA,GAMMA,XVEL,PHI,AB0,XU,XAX,BETA2
1525 IF(LO .NE. 0) WRITE (LO,400) BETA,GAMMA,XVEL,PHI,AB0,XU,XAX,BETA2
1526 .....
1527 : START OF DATA REDUCTION FOR INDIVIDUAL POSITIONS.
1528 :
1529 .....
1530 :
1531 : Calculation of values which are valid for all positions.
1532 :
1533 .....
1534 WRITE (LI,405)
1535 IF (LO .NE. 0) WRITE (LO,405)
1536 DO 185 I = 1,9,1
1537 J = (I-1) * 20
1538 YAWA(I) = DATA(20,J+11) * 10000
1539 YAWB(I) = DATA(20,J+13) * 10000
1540 185 PREFP(I) = DATA(20,J+14) * 100*1000
1541 .....
1542 : START OF DO LOOP
1543 :
1544 .....
1545 DO 270 I = ISTART,IEND,1
1546 DO 190 J = 1,9,1
1547 J1 = J * 2
1548 J2 = J * 2 + 1
1549 PA(J) = DATA(J1,1) * 0.01
1550 PB(J) = DATA(J2,1) * 0.01
1551 PA(J) = SECTA + SLOPEA * PA(J) + PREFP(J)

```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)


```

190 PB(J) = SECTB + SLOPER *PB(J) + PREFP(J)
.....
.....
.....
Approximate A-probe output.
.....
DO 195 I1 = 1,9,1
X1(I1) = YAWA(I1)
195 Y(I1) = PA(I1)
CALL MAT2(9,5,COEF,-4)
DO 200 I1 = 1,9,1
200 PAC(I1) = FNP(4,COEF,YAWA(I1))
.....
.....
FIND MAX. OUTPUT OF A PROBE.
.....
DX = 126.0
X0 = -40.0
205 DP = (FNP(4,COEF,X0) - FNP(4,COEF,(X0+DX)))
IF (ABS(DP).LT.0.001) GOTO 210
DPX = -2.0*COEF(3)*DX-6.0*COEF(4)*X0*DX-3.0*COEF(4)*DX*DX-
      12.0*COEF(5)**X0*DX*DX-12*COEF(5)*X0*X0*DX-4.0*COEF(5)*DX**3
X0 = X0 - DP / DPX
GOTO 205
210 ASL = X0
ASR = X0 + DX
AA0 = X0 + DX / 2.0
PAMAX= FNP(4,COEF,AA0)
PSAL = FNP(4,COEF,ASL)
PSAR = FNP(4,COEF,ASR)
PSA = (PSAL + PSAR) / 2.0
BETA = (PAMAX - PSA) / PAMAX
CPAMAX=(PAMAX - PSA) / (PTOTAL - PSA )
IF (IPRINT.NE.2HYE) GOTO 215
WRITE(LI,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
IF (LO.NE.0) WRITE(LO,390) ASL,AA0,ASR,PSAL,PAMAX,PSAR,CPAMAX
215 CONTINUE
.....
.....
APPROXIMATE B PROBE PRESSURES.
.....
DO 220 I1 = 1,9,1
X1(I1) = YAWB(I1)
220 Y(I1) = PR(I1)
CALL MAT2(9,5,COEF,-4)
IF (IPRINT.NE.2HYE) GOTO 225
WRITE(LI,410) I1,YAWA(I1),PA(I1),PAC(I1),DPA,YAWB(I1),PR(I1),PRC,
      *DPR
IF (LO.NE.0) WRITE(LO,415) I1,YAWA(I1),PA(I1),PAC(I1),DPA,
      *YAWB(I1),PR(I1),PRC,DPR
225 CONTINUE
.....
.....
CALCULATE AND PRINT QUALITY OF APPROXIMATIONS.
.....
DO 230 I1 = 1,9,1
PBC = FNP(4,COEF,YAWB(I1))
DPA = PA(I1) - PAC(I1)
DPB = PR(I1) - PRC
IF (IPRINT.NE.2HYE) GOTO 230
WRITE(LI,415) I1,YAWA(I1),PA(I1),PAC(I1),DPA,YAWB(I1),PR(I1),PRC,
      *DPR
230 CONTINUE
.....
.....
FIND MAXIMUM OUTPUT OF B-PROBE.
.....
X0 = 10.00
235 DPX = FND(4,COEF,X0)
IF (ABS(DPX).LT.0.001) GOTO 240
X0 = X0 - DPX / (2*COEF(3) + 6*COEF(4)*X0 + 12*COEF(5)*X0*X0)
GOTO 235
240 AR0 = X0
PRMAX = FNP(4,COEF,AR0)
IF (IPRINT.NE.2HYE) GOTO 245

```

Figure J-2. Listing of Data Reduction Program &ABRED.
(Continued on next page.)


```

639 WRITE (LI,395) ABO,PRMAX
640 IF (LO.NE. 0 ) WRITE (LO,395) ABO,PRMAX
641
642 245 CONTINUE
643   CPBMAX = ( PRMAX - PSA ) / ( PTOTAL - PSA )
644   GAMMA  = ( CPAMAX - CPBMAX ) / CPAMAX
645   XVEL   = 0.0
646   PHI    = 0.0
647   DO 250 I1 = 1,7,1
648     DO 250 I2 = 1,7,1
649       XVEL = XVEL + (COEXX(I1,I2) * GAMMA** (I2-1)) * BETA** (I1-1)
650       PHI  = PHI + (COEXP(I1,I2) * GAMMA** (I2-1)) * BETA** (I1-1)
651 250 IF (IPRINT.NE. 2HYES) GOTO 265
652   PSTAT = PAMAX * ( 1 - XVEL*XVEL ) ** 3.5
653   WRITE (LI,420) PSTAT
654   IF (LO.NE. 0 ) WRITE (LO,420) PSTAT
655   WRITE (LI,425)
656   IF (LO.NE. 0 ) WRITE (LO,425)
657   DO 260 I1 = 1,9,1
658     CPA = (PA(I1) - PSTAT) / (PAMAX - PSTAT)
659     YAW = YAWA(I1) - ABO
660     WRITE (LI,430) I1,YAW,CPA
661     IF (LO.NE. 0 ) WRITE (LO,430) I1,YAW,CPA
662 260 CONTINUE
663 265 CONTINUE
664   PHI = PHI * 180 / 3.14159
665   BETA2 = ATAN ((XU - XVEL * SIN(ABO * 3.14159 / 180) *
666 * COS(PHI * 3.14159 / 180)) /
667 * (XVEL * COS(ABO * 3.14159 / 180) * COS(PHI * 3.14159 / 180))) *
668 * 180 / 3.14159
669
670 C .....
671 C PRINT FLOW VECTOR QUANTITIES FOR INDIVIDUAL POSITIONS.
672 C .....
673   WRITE (LI,435) I,BETA,GAMMA,XVEL,PHI,ABO,BETA2
674   IF (LO.NE. 0 ) WRITE (LO,435) I,BETA,GAMMA,XVEL,PHI,ABO,BETA2
675   RDATA(1,I) = XVEL
676   RDATA(2,I) = PHI
677   RDATA(3,I) = ABO
678 270 CONTINUE
679
680 C .....
681 C STORE REDUCED DATA IN A DATA FILE.
682 C .....
683
684 IL = 1536
685 ISIZE(2) = 1536
686 WRITE (LI,440) NOLF
687 READ (LI,340) IFILE,ISECU,ICR
688 CALL CREAT (IDCB,IERR,IFILE,ISIZE,ITYPE,ISECU,ICR,IDCBS)
689 IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR
690 CALL OPEN (IDCB,IERR,IFILE,IOPTR,ISECU,ICR,IDCBS)
691 JJ = 17
692 IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR
693 CALL WRITF (IDCB,IERR,RDATA,IL)
694 JJ = 18
695 IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR
696 CALL CLOSE (IDCB,IERR,0)
697 JJ = 19
698 IF (IERR.LT. 0 ) WRITE(1,1111) JJ,IERR
699 WRITE (LI,445) IFILE,ICR
700 IF (LO.NE. 0 ) WRITE (LO,445) IFILE,ICR
701 STOP 7777
702 END
703
704 REAL FUNCTION FNP(NORDER,COEFF,ZX)
705 REAL COEFF(7)
706 A1 = COEFF(NORDER+1)
707 IF ( NORDER.EQ. 0 ) GOTO 02
708 DO 01 I1 = 1,NORDER,1
709   I = NORDER + 1 - I1
710   A1 = COEFF(I) + ZX * A1
711 01 FNP = A1
712 RETURN
713 END
714
715 REAL FUNCTION FND(NORDER,COEFF,ZX)
716 REAL COEFF(7)
717 REAL COEFFD(6)
718 DO 01 I=1,NORDER,1
719   COEFFD(I) = COEFF(I+1) * I
720   A1 = COEFFD(NORDER)
721   NORDR = NORDER - 1
722   IF( NORDR.EQ. 0 ) GOTO 03
723   DO 02 I1 = 1,NORDR,1
724     I = (NORDR + 1) - I1
725     A1 = COEFFD(I) + ZX * A1
726 02 FND = A1
727 03 RETURN
728 END

```

Figure J-2. Listing of Data Reduction Program &ABRED.

APPENDIX K

PLOTT PROGRAMS FOR REDUCED DATA

The plot programs &PLOTX, &PLOTY and &PLOTP can be used to produce plots of the results obtained from the A and B probe. They are all almost identical except for which quantities of the flow vector they plot and the corresponding limits of the plots. Only one program description and one flow chart are given and the differences between the three programs are pointed out where they appear.

First, the program asks the user to key in the name of the data file containing the reduced data along with its cartridge reference number. This file is then read into an array DATA(3,256). The user has to decide whether he would like a plot on the X-Y plotter or just on the screen. Plots on the screen are much faster than those from the X-Y plotter and it is often only necessary to get a fast idea of the general value of the reduced data. However, X-Y plots are rather useful for documentation purposes. Once this decision is made either way, the use of the plot has to be specified. This must be done at any time the program is used. The physical dimensions of the plot have to be matched to the particular needs of the user.

Plot sizes have to be given in inches times ten. One inch is set equal to 25 millimeters (instead of 25.4 mm) by

the HP plotter software. The values of XMIN and YMIN (lower left corner of plot) should not be smaller than 5.0 (0.5 inches or 12.5 mm), in order to leave sufficient space for the line titles. It is advisable to scale the lengths of the axes in a way that even measures in inches correspond to even numbers of the quantities plotted. For example, 10 degrees in yaw angle equivalent to 1 inch. Following are the limits of the quantities to be plotted:

For all programs: $0 \leq \text{circumferential position} \leq 256$

Program PCOTX: $0.12 \leq X \text{ (Mach number equivalent)} \leq 0.20$

Program PCOTP: $-4^\circ \leq \text{pitch angle} \leq 16^\circ$

Program PCOTY: $10^\circ \leq \text{yaw angle} \leq 50^\circ$

Before the programs are used, the operator should check to see if his data falls within these limits. If it exceeds any limits, adjustments have to be made in the corresponding program line #67.

In order to compare different sets of data it is often helpful to plot the data from two or more files on one plot. To avoid having the same grid plotted any time one set of data is plotted, the user has to specify whether he wants to have a full grid (frame) plotted or not. He is also given a choice of 7 different line styles in order to distinguish similar but different data. For details of the line styles and plot software details see Ref. 11.

Once all this input is given the desired program will produce a plot as specified. In case of the X-Y plotter the number one pen is selected automatically by the program.

Thus the user should make sure that a good pen of the right color is inserted in that slot. When the complete graph is drawn, the program will stop.

Figure K-1 gives a flow chart of the program while Fig. K-2 is a program listing.

Externals: CLOSE, DRAW, FXD, MOVE, OPEN, PLOT, READ, SET, VIEW, WINDOW

<u>Variable</u>	<u>Type</u>	<u>Description</u>
DATA(3,256)	Real	Reduced data array
IBUM	Integer	Dummy variable
ICR	Integer	Cartridge reference number
ID	Integer	
IDCB(144)	Integer	Data control block
IDCBS	Integer	Control block length (of IDCB)
IDUM	Integer	Dummy variable
IFILE(3)	Integer	Array containing file name
IGCB(192)	Integer	Graphic data control block
IL	Integer	Total number of words to be stored in raw data file (two words for one data value)
ILINE	Integer	Line style determinator
ISECU	Integer	Security code
ISIZE(2)	Integer	Array to specify file dimensions (1st word for number of records, 2nd for record length)
ITYPE	Integer	Type of data file
LU	Integer	Output device number (screen/plotter)
X(256)	Real	Data array for X values

<u>Variable</u>	<u>Type</u>	<u>Description</u>
XMAX	Real	Maximum value of physical plot size (right side)
XMIN	Real	Minimum value of physical plot size (left side)
Y(256)	Real	Data array for Y values
YMAX	Real	Maximum value of physical plot size (upper limit)
YMIN	Real	Minimum value of physical plot size (lower limit)

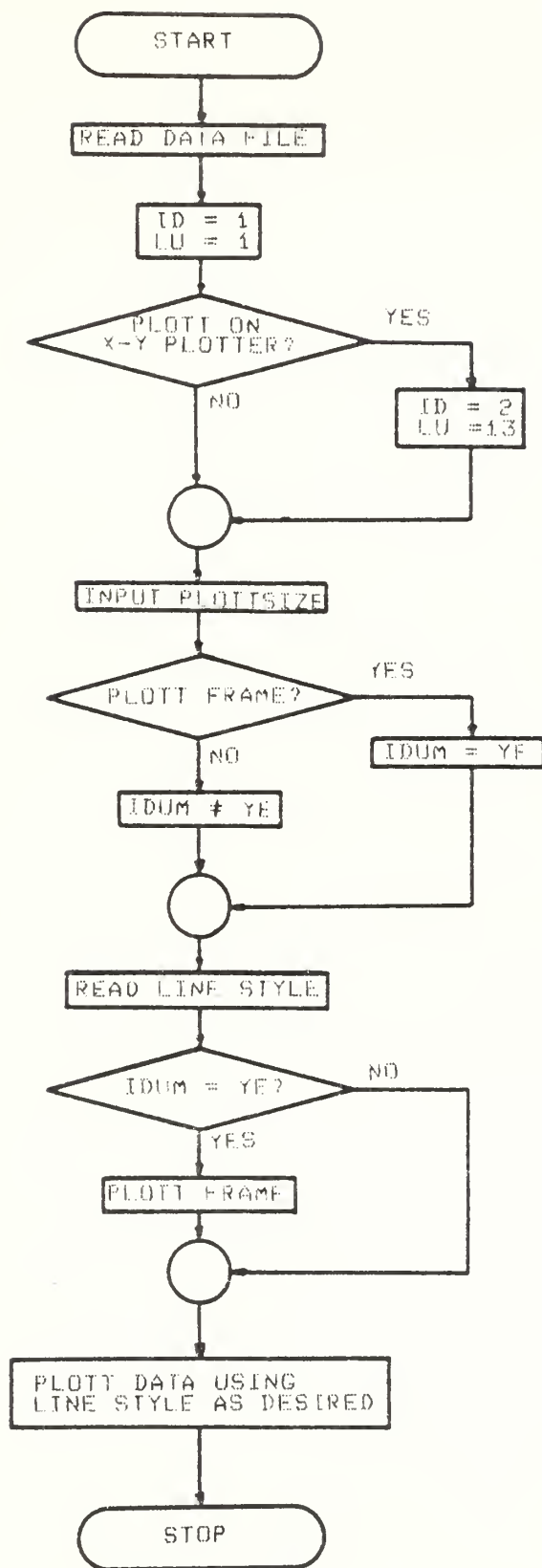


Figure K-1. Flow Chart of Plot Programs &PLOTX, &PLOTY or &PLOTTP.

PLOTX T=00004 IS ON CR00026 USING 00014 BLKS R=0000

```

001 FTN4,L
002 PROGRAM PLOTX (3,99)
003 .....
004 .....
005 THIS IS PROGRAM PLOTX(v=1)
006 .....
007 IT PLOTIS X (MACHNUMBER) DISTRIBUTIONS AS ESTABLISHED WITH
008 PROGRAM ABRED.
009 X IS EQUIVALENT TO MACHNUMBER AND GIVEN AS A FUNCTION OF
010 CIRCUMFERENTIAL POSITION.
011 .....
012 ACTUAL PLOTSIZE IS USER INPUT.
013 .....
014 .....
015 DIMENSION IGCB(122)
016 REAL DATA(4,256),X(256),Y(256)
017 INTEGER IDCBS(144),IFILE(3),ISIZE(2)
018 DATA IDCBS / 144/
019 DATA ISECU / 00/
020 DATA ITYPE / 1/
021 DATA IL / 2048/
022 DATA ISIZE(1) / 16/
023 DATA ISIZE(2) / 128/
024 100 FORMAT ("Enter the name of the data file!")
025 101 FORMAT ("Enter the CR number!")
026 102 FORMAT(" If you want the plott on the plotter, key PL, anythingels
027 *s for the terminal!")
028 103 FORMAT ("Enter Xplotmin!")
029 104 FORMAT ("Enter Xplotmax!")
030 105 FORMAT ("Enter Yplotmin!")
031 106 FORMAT ("Enter Yplotmax!")
032 107 FORMAT(" Do you need a complete new frame?"/" Answer YES or NO!")
033 108 FORMAT (" Enter line style (0 - 6)!")
034 149 FORMAT (" (3A2)")
035 1111 FORMAT (" STATEMENT #: "I3" ERROR #: "I4" DETECTED")
036 LI = LOGU(ISESSN)
037 WRITE (LI,100)
038 READ (LI,149) IFILE
039 WRITE (LI,101)
040 READ (LI,*) ICR
041 CALL OPEN (IDCB,IERR,IFILE,IOPTN,ISECU,ICR,IDCBS)
042 JJ = 1
043 IF (IERR.LT. 0) WRITE (LI,1111) JJ,IERR
044 CALL READF (IDCB,IERR,DATA,IL,LEN,1)
045 JJ = 2
046 IF (IERR.LT. 0) WRITE (LI,1111) JJ,IERR
047 JJ = 3
048 CALL CLOSE (IDCB,IERR,0)
049 IF (IERR.LT. 0) WRITE (LI,1111) JJ,IERR
050 LU = 1
051 ID = 1
052 WRITE (LI,102)
053 READ (LI,149) IBUM
054 IF (IBUM.EQ. 2HPL) ID = 2
055 IF (ID.EQ. 2) LU = 13
056 WRITE (LI,103)
057 READ (LI,*) XMIN
058 WRITE (LI,104)
059 READ (LI,*) XMAX
060 WRITE (LI,105)
061 READ (LI,*) YMIN
062 WRITE (LI,106)
063 READ (LI,*) YMAX
064 CALL PLOTX (IGCB,ID,1,LU)
065 CALL SETAR (IGCB,1.5)
066 CALL VIEWP (IGCB,XMIN,XMAX,YMIN,YMAX)
067 CALL WINDOW (IGCB,0.0,256.0,0.18,0.24)
068 WRITE (LI,107)
069 READ (LI,149) IDUM
070 WRITE (LI,108)
071 READ (LI,*) ILINE
072 CALL LINE (IGCB,ILINE)
073 IF (IDUM.NE. 2HYES) GOTO 05
074 CALL FXD (IGCB,2)
075 CALL PEN (IGCB,1)
076 CALL LGRID (IGCB,-16.,.01,0.0,0.12,4.0,2.0,1.0)
077 05 CONTINUE
078 CALL MOVE (IGCB,0.0,DATA(1,1))
079 DO 10 I = 1,256,1
080 XJ = 1.0
081 10 CALL DRAW (IGCB,XJ,DATA(1,I))
082 STOP 7777
083 END

```

Figure K-2. Listing of Reduced Data Plott Program &PLOTX.

LIST OF REFERENCES

1. F. Neuhoff, "Calibration and Application of a Combination Temperature-Pneumatic Probe for Velocity and Rotor Loss Distribution Measurements in a Compressor," Contractor's Report No. NPS67-81-03CR, December 1981.
2. R. P. Shreeve, J. M. Simmons, J. C. West, Jr., and K. A. Winters, "Determination of Transonic Compressor Flow Field by Synchronised Sampling of Stationary Fast Response Transducers," (Winter Annual Meeting of the Society of Mechanical Engineers, San Francisco, CA, December 1978).
3. R. P. Shreeve, A. G. McGuire and J. A. Hammer, "Calibration of a Two Probe Synchronised Sampling Technique for Measuring Flows Behind Rotors," ICIASF'79 Record, IEEE 79CH1500-8AES.
4. McCarville, P. A., "Hardware and Software Improvement to a Paced Data Acquisition System for Turbomachines," Master's Thesis, Naval Postgraduate School, Monterey, CA, June 1981.
5. Frank S. Cina, "Subsonic Cascade Wind Tunnel Tests Using a Compressor Configuration of DCA Blades," Master's Thesis, Naval Postgraduate School, Monterey, CA, June 1981.
6. H. Zebner, "Procedure and Computer Program for the Approximation of Data (with Application to Multiple Sensor Probes)," Contractor's Report No. NPS67-80-001CR, August 1980.
7. H. Weyer, "Bestimmung der zeitlichen Druckmittelwerte in stark fluktuierender Stromung, insbesondere in Turbomaschinen," [The Determination of Time-Weighted Average Pressures in Strongly Fluctuating Flows, Especially in Turbomachines], Deutsche Forschungs- und Versuchsanstalt fur Luft- und Raumfahrt, Forschungsbericht 74-34, (1974).
8. L. N. Krause, T. J. Dudzinski and R. C. Johnson, "Total Pressure Averaging in Pulsating Flows, Instrumentation for Airbreathing Propulsion," edited by A. E. Fuhs and M. Kingery for AIAA series, Progress in Astronautics and Astronautics, Volume 34, M.I.T. Press, (1974).
9. S. H. Chue, "Pressure Probes for Fluid Measurement," Prog. Aerospace Sci., 1975, Vol. 16, No. 2, pp. 147-223, Pergamon Press. Printed in Great Britain.
10. D. W. Byer and R. C. Pankhurst, "Pressure-probe methods for Determining Wind Speed and Flow Direction," National Physical Laboratory.
11. HP 92840A Graphics Plotting Software, Manual Part No. 92840-90001, Printed in U.S.A. April 1980.

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